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Air

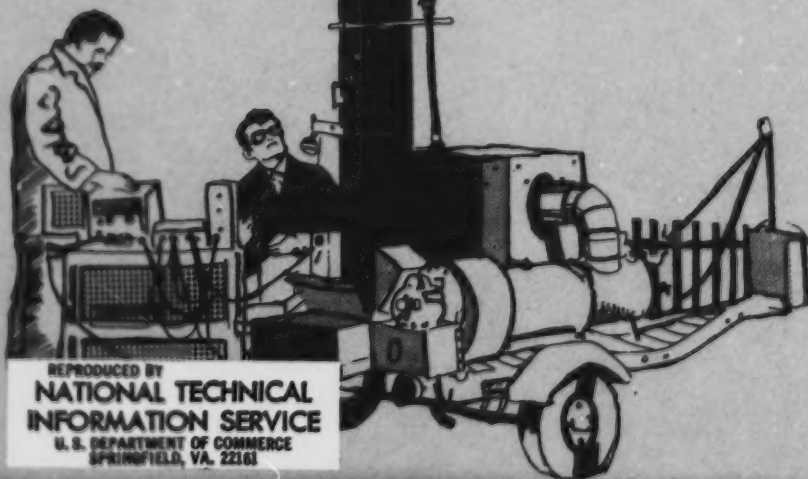
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APTI Course 439 Visible Emissions Evaluation

Student Manual



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16. ABSTRACT This manual is to be used by students who are learning how to evaluate ("read") visible emissions to the atmosphere from air pollution sources. Both black, grey, and white plumes are covered. The manual discusses sources of air pollution and describes visible emissions to be expected and the reasons why such may occur. A brief review of meteorological phenomena affecting stack plume behavior is given. Practices and procedures to be used in evaluating visible emissions of both the black/grey and other color nature are described in detail. The Ringelmann chart and its use are discussed. Equipment for generating visible emissions to be observed in training observers is described in detail.					
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AIR POLLUTION TRAINING INSTITUTE
MANPOWER AND TECHNICAL INFORMATION BRANCH
CONTROL PROGRAMS DEVELOPMENT DIVISION
OFFICE OF AIR QUALITY PLANNING AND STANDARDS

The Air Pollution Training Institute (1) conducts training for personnel working on the development and improvement of state, and local governmental, and EPA air pollution control programs, as well as for personnel in industry and academic institutions; (2) provides consultation and other training assistance to governmental agencies, educational institutions, industrial organizations, and others engaged in air pollution training activities; and (3) promotes the development and improvement of air pollution training programs in educational institutions and state, regional, and local governmental air pollution control agencies. Much of the program is now conducted by an on-site contractor, Northrop Services, Inc.

One of the principal mechanisms utilized to meet the Institute's goals is the intensive short term technical training course. A full-time professional staff is responsible for the design, development, and presentation of these courses. In addition the services of scientists, engineers, and specialists from other EPA programs, governmental agencies, industries, and universities are used to augment and reinforce the Institute staff in the development and presentation of technical material.

Individual course objectives and desired learning outcomes are delineated to meet specific program needs through training. Subject matter areas covered include air pollution source studies, atmospheric dispersion, and air quality management. These courses are presented in the Institute's resident classrooms and laboratories and at various field locations.

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FOREWORD

The Federal Government has discontinued the use of Ringelmann Number standards in Federal new source performance standards and has now based the determination of the optical density, or opacity of visible emissions from stationary sources, solely on opacity. Many State regulations have not made this change and continue to operate under a dual system in which Ringelmann Number is used in the evaluation of black or gray emissions and Equivalent Opacity is used in the evaluation of all other visible emissions.

This manual is designed to serve as wide an audience as possible and so continues to refer to both the Ringelmann Number and the Equivalent Opacity methods of evaluation. If opacity is now the only type of visible emission regulation in your State, please make the proper adjustments in the manual curriculum to reflect this regulation. If Ringelmann and Equivalent Opacity are currently viable in your State, your trainees should at least be aware of the Federal practice. A copy of the current Method 9 as published in the Federal Register is included in this manual.

This manual is intended for those students who need to become a qualified visible emissions evaluator for the first time. To become a qualified visible emissions evaluator the student must successfully complete a training school, normally of three days duration presented by a Federal, State or local air pollution agency, or

educational establishment. The training school consists of a series of lectures, slide and film presentations and the actual training of the students to evaluate the opacity of visible emissions. The first half of the school provides sufficient background material such that competent evaluations of the opacity of visible emissions can be made in the field during enforcement operations. The second half includes the qualification steps in reading visible emissions. During the second half, students needing only recertification can be included. They need not repeat the first half.

Batelle-Columbus Laboratories is credited for most of the material in this manual. Under contract with EPA, they prepared a training package. Because there has been much time elapsed since completion of their contract and due to many changes in regulations and techniques, EPA has found it appropriate to modify the package prepared by Batelle.

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COURSE OBJECTIVES

This manual is intended for use by students that have not been certified as a qualified observer. The contents of this manual will provide the qualified observer with adequate background knowledge needed to help substantiate any violation that he may record.

At the conclusion of this course the student should be able to:

- (1) Visually measure (i.e., without the use of devices) the shade or opacity of visible air pollution emissions for a set of 25 shades of white smoke and 25 shades of black smoke:
 - (a) With an average error not to exceed 7.5 percent opacity in each category.
 - (b) With an error not to exceed 15% opacity (or $3/4$ of a Ringelmann Number) on any one reading in each category.
- (2) Define Ringelmann Number and Equivalent Opacity in the following manner:
 - (a) The Ringelmann Number gives shades of gray by which the density of columns smoke rising from a source may be compared. It is a system whereby graduated shades of gray, varying by five equal steps between white and black, may be accurately reproduced by means of a rectangular grill or by

black lines of definite width and spacing on a white background.

- (b) Equivalent Opacity is an extension of the Ringelmann Chart method of quantifying visible emissions. The opacity or degree to which a non-black or grey plume obscures an observer's view is related to the extent to which a black or grey plume of a particular Ringelmann Number obscures an observer's view. For example, a Ringelmann Number 2 plume is equivalent to a plume having 40% opacity.

- (3) List the following essential conditions for correctly evaluating the plume:

- (a) Keep the sun in the 140° sector to your back.
- (b) Try to have a contrasting background.
- (c) Readings should be taken at approximately right angles to the plume direction and at any distance to obtain a clear view of the emissions.
- (d) Readings should be made through the most dense part of the plume and in that portion of the plume where condensed water vapor is not present.
- (e) When observing emissions from rectangular outlets, readings should be at approximately a right angle to the longer axis of the outlet.
- (f) The observer shall not look continuously at the plume, but instead shall observe the plume momentarily at 15-second intervals.

- (4) List the following essential items to be recorded on the training form:

- | | |
|----------|--------------------|
| (a) Name | (d) Wind speed |
| (b) Date | (e) Wind direction |
| (c) Time | (f) Sky condition |

and properly fill out these items for his field recording form.

- (5) List at least four of the following techniques (even though not generally in use) for measuring visible emission:

- | | |
|-------------------------|----------------------|
| (a) Smoke guide | (d) Smokescope |
| (b) Umbrascope | (e) Smoke tintometer |
| (c) Photo-electric cell | |

- (6) Differentiate between the plumes emitted from combustion processes and industrial processes.
- (7) Identify condensed water vapor plumes and breakpoint.
- (8) Make application of his knowledge of meteorology in the following manner:

- (a) Estimate wind speeds from 0-18 mph using the Beaufort Scale
- (b) Define wind direction and estimate wind direction
- (c) Estimate sky condition (percentage of cloud cover)
- (d) List the distinguishing characteristics of high and low pressure areas
- (e) Identify on a weather map the symbols for the following:

high pressure area

low pressure area

cold front
warm front
occluded front
stationary front

- (f) List at least two points of information obtained from a weather map which the smoke inspector could find useful in planning his activities.

- (9) Testify in court as an effective expert witness concerning visible emissions observations. To demonstrate his capability he should be able to:

- (a) Identify 8 of the 10 criteria for being an expert witness
- (b) List 5 of the 8 rules for behavior on the witness stand
- (c) Cite the legal precedents set in the California appeal cases concerning visible emission regulations.

- (10) State the essential elements of his local or state visible emission code.

- (11) List the primary components of the emission generator:

- (a) Combustion chamber for generating black smoke
- (b) Generator's exhaust manifold for white smoke
- (c) Transmissometer
- (d) Auxiliary blower
- (e) Recorder or indicator.

CHAPTER I.
VISIBLE EMISSIONS:
THEIR CAUSE AND REGULATION

1.1 Visible emissions are composed of small solid or liquid particles or colored gases.

1.2. The more opaque a plume is from a specified source, the more effluent is being emitted, all other particulate and flow characteristics being equal.

1.3. Some invisible pollutants such as colorless gases cannot be detected by the naked eye, e.g., SO_2 , CO.

1.4. The micron (μ) is a unit of length used to measure particle diameters. It is equal to 0.001 (one thousandth) of a millimeter.

1.5. Particles between 0.1 and 100 μ are considered suspended particulates in the atmosphere and are those normally collected by high volume samplers.

1.6. Particles between 0.1 and 1.0 μ are most capable of causing haze. They cause sunlight to scatter in the visible wavelengths (0.4 to 0.7 μ) of light. Larger particles are visible because they intercept or reflect the sunlight. Smaller particles have little effect on the light and are invisible.

1.7. Visible air contaminants can be classified as

- | | |
|-------------|-------------------|
| (a) Smoke | (e) Fumes |
| (b) Soot | (f) Mist |
| (c) Fly ash | (g) Certain gases |
| (d) Dust | (h) Vapor |

1.8. Plumes of condensed water vapor are visible, but uncombined water is generally not considered a pollutant.

1.9. Smoke is a visible effluent resulting from incomplete combustion and consisting mostly of soot, fly ash, and other solid or liquid particles.

1.10. Soot is a cluster of carbon particles saturated with tar. It is formed by the incomplete combustion of carbon-containing material. It is the principal cause of the blackness of a smoke plume.

1.11. Fly ash is unburned material arising from the combustion of fuel. It has sufficiently small size that it can remain suspended in the air. A pure fly ash plume will be of a light-brown or cream color.

1.12. Fumes consist of metal or metal oxide particles less than $1\ \mu$ in diameter. These are minute solid particles generated by the condensation of vapors from solid matter after volatilization from the molten state.

1.13. Dust consists of solid particles, generally greater than $1\ \mu$ in diameter, released to the air by processes such as crushing, grinding, drilling, sweeping, sanding, demolishing, etc. Since they are larger than the smoke or fume particles, they will settle to the ground faster.

1.14. Mist consists of liquid particles or droplets which are not composed of pure pollutant but contain it in solution or suspension. The droplets are of the size of fog droplets (about 10 μ - ranging from 2 to 200 μ).

1.15. Gas is fluid, such as air that has neither independent shape or volume but tends to expand indefinitely. Two visible pollutant gases are nitrogen dioxide (NO_2), which is brown to yellow, and chlorine, which is greenish yellow.

1.16. Vapor is the gaseous phase of a substance that at normal temperature and pressure, is a liquid or solid, e.g., vapor from gasoline.

1.17. Most visible plumes are composed of particulates. The reasons for particulates being objectionable are their effects on

- | | |
|-----------------------|----------------|
| (a) Materials | (d) Health |
| (b) Visibility | (e) Vegetation |
| (c) Incoming sunlight | |

The effects of Items (a) through (e) are discussed in 1.18 through 1.22.

1.18. Materials. Particulates deposited on clothes, automobiles, or houses must be washed off. When particulates are accompanied by sulfur dioxide and moisture, the rate of corrosion increases.

1.19. Visibility. Particulates in the air reduce the distance that one can see. If this visual range is decreased enough, it can cause unsafe operation of vehicles and aircraft.

1.20. Incoming sunlight. Particulate matter in the air can cause the sun's rays to be reflected or scattered, reducing the heat and light reaching the earth's surface.

1.21. Health. Increases in respiratory illness and even deaths may occur from high particulate concentrations, especially when sulfur dioxide concentrations are also high. Bronchitis patients will experience symptoms; particles less than 5 μ in diameter can reach the lungs.

1.22. Vegetation. Cement dust can reduce vegetation growth and cause its damage. Fluoride dust in the presence of water can damage leaves. If the fluoride dust is deposited on plants that are eaten by animals, the animals can contract fluorotic poisoning.

1.23. Regulations for restricting particulate emissions are in common use. The regulations are typed by

- (a) Weight concentration, which states the limit in relation to amount of flue gas emitted:
e.g., 0.20 lb of particulates/ 1000 lb of flue gas; 0.03 grains/std cu ft of flue gas at atmospheric pressure and 60°F.
- (b) Mass emission and process weight, which states the limit in relation to the amount of material processed, e.g., 12 lb/hr of particulate for 10,000 lb/hr of process weight.
- (c) Limitation on basis of thermal input in terms of British thermal units (Btu). Example: For coal-fired boilers of less than 10 million Btu/hr heat input, the emission of fly ash and other particulate matter shall not exceed 0.6 pound of particulate matter/million Btu.

- (d) Boundary-line measurements of ambient air quality. Example: The suspended particulate outside the factory fence shall not exceed a 24-hour average of 200 micrograms/m³.
- (e) Plume shade density or opacity in terms of Ringelmann Number or its extension to Equivalent Opacity. Example: No emission as dark or darker than that designated as No. 2 on the Ringelmann Chart is allowed for a total of more than 3 minutes in 1 hour.

1.24. The regulation using the Ringelmann Chart and Equivalent Opacity is the least time consuming and the least expensive for enforcement by the air pollution officer.

1.25. Method 9 (40 CFR Part 60 App. A.) refers to all visible emissions, black, white, or colored in terms of opacity. (See current Method 9 procedures later in this manual.)

Suggested Additional Reading

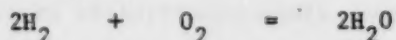
"Effect on the Physical Properties of the Atmosphere," E. Robinson, in Air Pollution edited by A. C. Stern. Vol. 1, second edition, 1968. Vol. 2, third edition, 1976. Academic Press, 111 Fifth Avenue, New York, NY 10003.

CHAPTER II. PRINCIPLES OF COMBUSTION

2.1. Combustion or burning is the rapid oxidation of a fuel. This chemical reaction between the fuel and oxygen requires a high temperature.

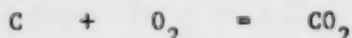
2.2. Most common fuels contain carbon and hydrogen plus sulfur and ash materials. The ash does not burn, but the carbon, hydrogen, and sulfur each combine with oxygen and produce heat and waste gases.

2.3. Two parts hydrogen plus one part oxygen equals two parts water vapor:



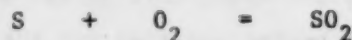
A pound of pure hydrogen will release 62,028 Btu (British thermal units) of heat when it burns.

2.4. One part carbon plus one part oxygen equals one part carbon dioxide:



A pound of pure carbon will release 14,544 Btu when it burns.

2.5. One part sulfur plus one part oxygen equals one part sulfur dioxide:



A pound of pure sulfur will release 4,050 Btu when it burns. The sulfur therefore produces little heat but does produce a major air pollutant.

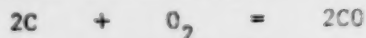
2.6. In practice, combustion does not involve pure hydrogen, carbon, sulfur, or oxygen: oxygen is mixed with nitrogen in the air; in fuel, the hydrogen is

compounded with the carbon to form complex tars, resins, etc.; the sulfur is combined with other compounds or with elements such as iron.

2.7. Thus, to make sure in practice that all the carbon and hydrogen combine with oxygen, three conditions must be maintained in the furnace--the "three T's of combustion":

- (a) Sufficient time for the molecules of oxygen to come into contact with the molecules of fuel.
- (b) An adequately high temperature to sustain the reaction.
- (c) Turbulence or mixing to make sure that all the molecules of fuel are combined with the oxygen in the air.

2.8. One result which will occur if the "three T's" are not sufficient is that carbon monoxide will be formed, since insufficient oxygen will combine with the fuel--two parts carbon plus one part oxygen equals two parts carbon monoxide:



2.9. Even with the "three T's," furnaces are generally not so efficient as to insure that every molecule of hydrogen and carbon will be combined with a molecule of oxygen. One remedy for this is to use more oxygen than is theoretically necessary. This extra oxygen is supplied by using excess air. However, there is a penalty for using this excess air, since some of it becomes heated and goes out the stack as part of the flue gas. This heat used to raise the temperature of the excess air is wasted.

2.10. Methods used to increase the effect of the "three T's of combustion" in furnaces which are listed below include the following:

2.11. Temperature

- (a) Heat the air before it enters the furnace.
- (b) Insulate the combustion chamber of the furnace.

2.12. Turbulence

- (a) Put baffles in the combustion chamber.
- (b) Introduce jets of air which stir up the air within the furnace as well as adding more air.

2.13. Time

- (a) Use baffles that also cause the fuel and air to remain in the combustion chamber longer.
- (b) Build the combustion chamber large enough so that the fuel and air will remain inside long enough for the combustion to be completed.

2.14. If some of the fuel does not receive enough air or heat to burn all the carbon, the ash will contain some pieces of partially burned or unburned carbon. When these particles are deposited on something, the deposit is called soot. When the particles remain in suspension in the flue gas, they form a black cloud called smoke.

2.15. If a furnace produces smoke, either the fuel and air are not in balance or the "three T's of combustion" are not being satisfied. One should look for one or more of the following conditions:

- (a) Insufficient air for the amount of fuel;
- (b) Too much air, which chills the flame before combustion is complete;
- (c) Insufficient turbulence of the air through the fuel;
- (d) Cold furnace when the fire is first lit or is burning at a low load--this is often accompanied by excessive air leaking into the furnace through doors and other holes.

2.16. All fuels or combustible materials, whether solid, liquid, or gas, are burned as a gas. Before it will burn, a solid or liquid must be heated until it is transformed into the gaseous or vapor state.

Movie: "The Three T's of Combustion"

2.17. Several components of the kerosene lamp are analogous to the components of other combustion units, whether they be coal- or oil-burning furnaces, incinerators, internal combustion engines, or other devices. The necessity for time, temperature, turbulence, and oxygen is universal among all combustion devices including the simple use of the kerosene lamp.

2.18. The parts of a kerosene lamp include:

- (a) The glass container at the base of the lamp where the kerosene is stored; this corresponds to a coal bunker or fuel tank.
- (b) The wick through which the kerosene is transferred from the storage to the burning area; this is similar to a coal stoker or a fuel line and fuel pump.
- (c) The grate where the fuel is burned.
- (d) The tuyere or diffuser above the top of the wick; the tuyere breaks up the fuel for better mixing with the air. Its function resembles that of an atomizer in a fuel burner, an injection nozzle in a diesel engine, or a carburetor in a gasoline engine.
- (e) The lamp chimney, which serves as an enclosed area in which the combustion can take place and also as an outlet for the exhaust gases. The combustion area corresponds to the combustion chamber of a coal furnace or jet engine and to the cylinder of an automobile. The exhaust portion is similar to a smoke stack or a tail pipe.

2.19. There are several examples given in the film which emphasize that incomplete combustion will occur if any one of the "three T's of combustion" is lacking.

2.20. Without the tuyere to diffuse the fuel, there is a smoky fire because the fuel cannot be intermixed with a sufficient amount of air for complete combustion.

2.21. Even with the tuyere the flame remains smoky, because the cool ambient air reduces the temperature of the kerosene-air mixture below the combustion temperature. When the chimney is placed on the lamp, the air can enter the lamp only below the tuyere. The fuel and air above the tuyere can circulate around in the wide part of the lamp chimney thus remaining at a high temperature for a time sufficient for complete combustion.

2.22. At first, the lamp chimney glass is cold and it cools the fuel-air mixture, causing a smoky flame. As the chimney warms up, the glass radiates heat back to the air-fuel mixture within and maintains the combustion temperature. The design of the interior of furnaces and the choice of refractory material to line the walls are directed toward reflecting the heat of combustion on particular zones or areas within the furnace.

2.23. If there is too much air for the amount of fuel, then some of the heat is used to warm the excess air and is wasted. The temperature of the gas leaving the combustion area is reduced.

2.24. If there is insufficient air for the amount of fuel, the temperature of the exhaust gases will wise but there will be a dense cloud of black smoke. This indicates that fuel is being wasted. A diesel engine can be adjusted to give more power by using excess fuel, although with the detriment of creating a black plume.

2.25. The film mentions two other ways of increasing the amount of air and eliminating smoky conditions besides controlling the amount of air entering the lamp below the flame:

- (a) Building a higher chimney so that the air pressure from the bottom to the top of the lamp chimney is increased. This increased draft pulls air into the combustion chamber at a greater rate.
- (b) Raising the bottom of the lamp chimney above its base, allowing air to enter above the grate. This additional overfire air eliminates the smoky flame, but it also cools the flame causing it to flutter and have a smoky tip.

Suggested Additional Reading

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CHAPTER III.
COMBUSTION OF FUEL OIL -
CORRECT PRACTICES

Classification of Fuel Oil

3.1. The crude oil that is pumped out of oil wells consists of 83 to 87 percent carbon and 10 to 14 percent hydrogen combined as hydrocarbons. It also contains traces of oxygen, nitrogen, and sulfur.

3.2. The crude oil is refined; this consists of separating and recombining the hydrocarbons of the crude oil into gasoline, fuel oil, etc. The refining process includes distillation and, often, cracking.

3.3. By boiling the crude oil, distillation separates the hydrocarbons into groups or "fractions" which have the same range of boiling points. The fractions also vary in density.

3.4. The lighter fractions, such as naphtha, gasoline, kerosene, and gas oil, are called the distillates. The heavier fractions include asphalt and the heavy fuel oils, are called residuals. During distillation, the sulfur-bearing compounds and the ash originally present in the crude oil are concentrated in the residual fractions.

3.5. Products of simple distillation are called straight run. Additional yield of gasoline can be obtained by cracking the heavier fractions.

3.6. Cracking consists of changing the hydrocarbon structure of the oil. This is done by decomposing the oil through the application of heat and pressure with or without a catalyst. The resulting products then are distilled again into heavy and light fractions.

3.7. There are five grades of oil used as fuel oil, labeled as Numbers 1, 2, 4, 5, and 6. Number 6 is often called Bunker C. There no longer is a Number 3 oil.

3.8. Numbers 1 and 2 are distillate fuel oils generally used for home oil furnaces and hot-water heaters.

3.9. Numbers 4, 5, and 6 are residual fuel oils. Both Number 4 and Number 5 are used in commercial establishments, large apartments, and industrial plants.

Bunker C (Number 6) is used in ocean-going ships, power generation plants, and larger commercial and industrial burners which use over 50 gallons of oil per hour.

3.10. Each of these oils has a set of standard specifications which distinguish it from the other oils. These specifications may include flash-point temperature, water and sediment percentage, gravity, ash, and sulfur content, viscosity, and others.

3.11. The viscosity and the ash and sulfur contents are the major characteristics that affect air pollutant emissions.

3.12. The relative ease or difficulty with which an oil flows is its viscosity. It is measured by the time in seconds a standard amount of oil takes to flow through a standard orifice at a standard temperature (100°C or 122°F).

3.13. Viscosity indicates how oil behaves when it is pumped and shows when it must be preheated for handling. Numbers 5 and 6 fuel oils are high viscosity oils and often require preheating facilities.

3.14. The sulfur content of fuel oil may vary from a trace to 5 percent while the ash may be as high as 0.3 percent by weight. The distillate fuel oils are limited by specification to less than one percent sulfur and Numbers 4 and 5 fuel oil are limited to no more than 0.1 percent ash.

3.15. The sulfur content of the residual fuel oil grades can be reduced by desulfurization processes or by blending low sulfur oils with the higher sulfur oils.

3.16. Crude oil contains thousands of hydrocarbon compounds which are classified as paraffins, naphthene, aromatics, resins, and asphalt.

3.17. If an oil is high in paraffins, the temperature of the flame will cause them to decompose into lighter and more volatile fractions which burn easily.

3.18. Aromatics do not readily decompose, but at temperatures at which they do, cracking will occur which can produce tar, smoke, and soot.

3.19. The olefins may crack and form compounds which are hard to burn.

Oil Burner Types

3.20. The principal types of oil burners which have been developed demonstrate a capability of coping with many possible variations in oils.

3.21. Oil burners do not burn oil. They proportion the air and oil and mix them in preparation for burning.

3.22. Since all fuels burn as a vapor, the liquid oil must either be converted to a gas in the burner (vaporized) or divided into such small particles or droplets (atomized) that heat within the combustion zone of the furnace will vaporize the fuel during its residence time in the combustion chamber of the furnace.

3.23. If the temperature of flame in the combustion chamber is too low, incomplete combustion and smoke emission will result. Cooling of the flame can occur when the combustion chamber is too small or too much air is introduced.

3.24. Oil burns like an onion peels, so it is necessary for turbulence to provide sufficient air to complete the combustion of each successive layer. Consequently, it is important to mix the air and oil.

3.25. Vaporizing burners gasify the oil by heating it within the burner. These burners are limited in the range of fuels they can handle and are used only for some residential furnaces and water heaters.

3.26. Atomizing of fuel oil can be accomplished in three ways:

- (a) Using steam or air under pressure to break the oil into droplets
- (b) Forcing oil under pressure through a nozzle
- (c) Tearing the oil film into drops by centrifugal force.

All three methods are used in burners.

3.27. With high-pressure steam - or air - atomizing burners, the steam or air is used to break up the fuel-oil stream at the burner tip. The auxiliary fluid, moving at high velocity, atomizes the slower moving oil stream as the mixture is emitted in the furnace. The combustion air is introduced through registers around each burner. When steam is used, it prevents the entering-oil temperature from dropping. This aids the flow of high-viscosity oil and improves atomizing characteristics.

3.28. Oil-pressure atomizing burners depend on high fuel pressure to cause the oil to break up into small droplets upon passing through the orifice.

3.29. Rotary-cup burners provide atomization by centrifugally throwing the fuel from a rotating cup or plate. These burners can be divided into two classes--horizontal rotary and vertical rotary. The vertical rotary is used only for domestic burners (under 10 gallons per hour).

3.30. Horizontal rotary cup burners are used for the residual fuel oils. The oil is distributed on the cup or plate in a thin film. The primary air from the burner fan is discharged through an air nozzle which has vanes to give the air a rotary motion opposite that of the oil. Additional air for combustion--secondary air--must also be injected into the combustion chamber for complete burning.

3.31. Mechanical atomizing burners employ both high oil pressure and centrifugal action. The fuel oil is given a strong whirling action before it is released into the orifice. These are the burners most often found at large steam power plants.

3.32. The key to optimum oil burner operation is careful control of fuel viscosity. A given burner functions properly only if the viscosity at the burner orifice is held between narrow limits.

3.33. If the viscosity is too high, effective atomization does not take place. If the viscosity is too low, oil flow through the orifice is too great, upsetting the balance between combustion air and fuel.

3.34. Most heavy residual oil must be warm to allow pumping. Preheaters are used to heat the oil and keep it flowing. For high-viscosity oils, the preheater is likely to be located at the supply tank. With oils of lower viscosity, preheaters are often located at the burner.

3.35. Before the oil reaches the burner, it is passed through a strainer or filter to remove the sludge. This filtering process prolongs pump life, reduces burner wear, and increases combustion efficiency.

3.36. The most important consideration in combustion chamber design is heat release, or British thermal unit release per cubic foot of furnace volume. Too high a heat release will result in excessive furnace temperatures. Too low a heat release will result in excessive cooling of the flame and smoking fires.

3.37. The size of the combustion chamber will determine the heat release. The shape of the chamber will prevent the flame from impinging on the sides of the furnace where it would cool, resulting in incomplete combustion and smoke.

3.38. Draft systems can be classified as natural, induced, or forced, or combinations of these.

3.39. Natural draft results from the difference in pressure between the stack and the outside air. Stacks that are too small for the firing rate will create back pressure. Too large a stack will cause the same conditions because of internal turbulence and too cool a stack temperature.

3.40. Induced draft systems require a fan that sucks combustion products through the boiler and forces them up the stack.

3.41. Forced-draft systems suck air in from the boiler room, push it into the boiler, and force the combustion products up the stack.

3.42. The burning of oil can produce sulfur oxides, inorganic ash, nitrogen oxides, carbon, and unburned hydrocarbons. The sulfur oxides and inorganic ash are attributable to the fuel. The air contaminants affected by burner design and operation are carbon, carbon monoxide, aldehydes, organic acids, and unburned hydrocarbons.

3.43. If a burner is operated properly, no visible emissions should be caused by oxidizable air contaminants, and the concentrations of items such as aldehydes and carbon monoxide should be negligible. Thus, when an oil-burning system smokes, emits appreciable odor, or causes eye irritation, there is something wrong in atomization, mixing, or burning. The burner and fuel may not be compatible or the burner may not be properly adjusted.

3.44. Incomplete atomization of the oil caused by improper fuel temperature, dirty, worn, or damaged burner tips, or improper fuel or steam pressure may cause the furnace to smoke.

3.45. A poor draft or improper fuel-to-air ratio may also cause smoking.

3.46. Other factors that may cause smoking are poor mixing and insufficient turbulence of the air and oil mixture, low furnace temperatures, and insufficient time for fuel to burn completely in the combustion chamber.

3.47. There are two kinds of hydrocarbon combustion--hydroxylation and decomposition (cracking).

3.48. Hydroxylation or blue-flame burning takes place when the hydrocarbon molecules combine with oxygen and produce alcohols or peroxides that split into aldehydes and water. The aldehydes burn to form CO_2 and H_2O .

3.49. Decomposition or yellow-flame burning takes place when the hydrocarbons "crack" or decompose into lighter compounds. The lighter compounds then crack into carbon and hydrogen, which burn to form CO_2 and H_2O . A mixture of yellow- and blue-flame burning is ideal.

Boiler Types

3.50. The vast majority of combustion equipment is used to heat or vaporize water. These boilers and heaters fall into three general classifications: fire-tube, water-tube, and sectional.

3.51. In fire-tube boilers, the heated gases resulting from combustion pass through heat-exchanger tubes while water, steam, or other fluid is contained outside the tubes.

3.52. Fire-tube boilers make up the largest share of small- and medium-size industrial boilers including the Scotch marine and fire-box types.

3.53. In all water-tube boilers, the water, steam, or other fluid is circulated through tubes while the hot combustion gases pass outside the tubes. All large boilers for steam generation are of this type. The smallest and largest industrial units are likely to be of a water-tube design.

3.54. Sectional boilers use irregularly shaped heat exchangers and cannot be classified as either water-tube or fire-tube types. Hot combustion gases are directed through some of these passages, transferring heat through metal walls to water or steam in other passages. These units are manufactured in identical sections which can be joined together. A sectional boiler consists of one or more sections.

Soot Blowing

3.55. Whenever fuels of measurable ash content are burned, some solids such as carbon and inorganic ash adhere to heat-transfer surfaces in the combustion equipment. These deposits must be removed periodically to maintain adequate heat-transfer rates. It is common practice to remove these deposits with jets of air or steam from a long, retractable soot blower while the combustion equipment is in operation. These removed soot particles are entrained in the combustion gases. Thus, during these periods of soot blowing the plume may have an excessive opacity.

3.56. Whenever residual fuel oils or solid fuels are burned in large steam generators, tube cleaning is usually conducted at least once during every 24 hours of operation. At many power plant boilers, soot blowers are operated automatically at 2- to 4-hour intervals.

3.57. When tubes are blown at 2- to 4-hour intervals, there is little increase in the opacity of stack emissions. Intervals of 8 hours or more between soot blowing can result in excessive visible opacities.

Black Smoke and White Smoke

3.58. When residual oils or solid fuels are burned in a deficiency of oxygen, carbon particles and unburned hydrocarbons impart a visible blackness to the exit gases.

3.59. Visible emissions ranging from gray through brown to white can also be created by the combustion of hydrocarbon fuels, particularly liquid fuel.

3.60. White or non-black smoke is the result of finely divided particulates--usually liquid particles--in the gas stream. These non-black plumes generally are caused by vaporization of hydrocarbons in the combustion chamber. This is sometimes accompanied by cracking and the subsequent condensation of droplets. White smoke frequently is attributed to excessive combustion air or loss of flame.

3.61. Visible plumes of greater than 40 percent opacity are frequently observed at large oil-fired steam generators, where incomplete combustion is a relative rarity. These opaque emissions are commonly attributed to inorganic particulates and sulfuric acid aerosols formed by the combination of sulfur trioxide, moisture, and flue gases. The condensation of the sulfuric acid aerosol may be enhanced by the presence of particulate matter, which provides condensation nuclei.

Particulates

3.62. Where combustion is nearly complete, inorganic ash constitutes the principal particulate emission. The quantity of these inorganic solid particulates is entirely dependent upon the fuel. Distillate fuels do not contain appreciable amounts of ash. In residual oils, however, inorganic ash-forming materials are found in quantities up to 0.3 percent by weight, but not to exceed 0.1 percent for grades 4 and 5. However, even that amount, when emitted from efficient burning, is not likely to exceed air pollution control statutes.

3.63. The particulates emitted from normal oil firing are principally in the submicron range of diameters where they can cause scattering of light. Over 85 percent of the particles from efficient oil burning are less than 1 micron in diameter.

3.64. If incomplete combustion occurs and carbon or hydrocarbon particles are emitted, then the average particle size is larger.

3.65. If a light fuel oil is burned in a deficiency of oxygen, the resulting carbon particles are likely to be very fine. If a residual fuel oil is incompletely burned, by heating it to a temperature of only 200-300°C and then cooling it, the carbon particles are likely to be in the form of cenospheres. Cenospheres are hollow, black, coke-like spherical particles of low density usually having a minimum dimension of 0.1 micron.

3.66. Particulates emitted from residual fuel oil combustion consist of 10 to 30 percent ash, 17 to 25 percent sulfate, and 25 to 50 percent cenosphere.

Sulfur Trioxide

3.67. Of the sulfur contained in fuel oil, about 95% shows up in the exhaust gases as sulfur dioxide, a colorless gas. Up to 5% of the sulfur may be converted to sulfur trioxide. If the SO_3 comes into contact with surfaces below the dew point of the gas, the SO_3 combines with water vapor to produce sulfuric acid. This sulfuric acid mist is visible.

3.68. Concentrations of SO_3 are negligible in small equipment, even when fired with high-sulfur fuel oils. As the equipment sizes and firebox temperatures increase, SO_3 concentrations increase rapidly.

3.69. Large steam generators may emit SO_3 mist of greater than 40 percent opacity when fired with oil of greater than 1.0 percent sulfur.

3.70. Sulfur trioxide tends to acidify particulate matter discharged from combustion equipment. This is commonly evidenced by acid spots on painted and metallic surfaces as well as on vegetation. Acid damage generally is the result of soot blowing.

3.71. Formation of SO_3 depends upon several factors. Concentrations of sulfur trioxide increase with increases in

- (a) Combustion chamber temperature;
- (b) Oxygen concentration;
- (c) Vanadium, iron, and nickel oxide content of the fuel oil.

3.72. The visible plume from a large oil-fired unit normally varies from white to brown, depending upon weather conditions and the composition of the particulate matter.

3.73. In some cases, the SO_3 plume will be detached from the stack. It will become visible at the point where the sulfuric acid mist is cooled below its dew point.

3.74. Deposits of dirt which cannot be removed by the normal soot blowing of the heat-exchanger tubes act as catalysts oxidizing SO_2 to SO_3 , with an increased opacity of the plume resulting. These deposits can be removed by washing, but only at the infrequent intervals when the steam generator is out of service.

Control Equipment

3.75. Until recently, the only air pollution control devices that have found ready acceptance on oil-fired power plant boilers were multiclones and low draft loss separators used to control particulates during soot blowing. Now some oil-fired power plants have installed electrostatic precipitators to control the particulate emissions.

3.76. Use of cyclone type collectors during normal operations is worthless since the collectors are not efficient in removing particulates of less than 5-microns diameter, which is the range in which over 95 percent of the oil-fired emissions lie.

3.77. The use of electrostatic precipitators for oil-fired power plants is limited to areas where restrictive legislation requires low particulate emissions and low opacity of stack effluents. They collect nearly all the particulates including the liquid sulfuric acid droplets. The particulate loading may be decreased by as much as 90 percent and the SO_3 emission may be cut in half.

Suggested Additional Reading

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CHAPTER IV.
COMBUSTION OF COAL
AND ITS CONTROL

Classification of Coal

4.1 The types of coal are

- (a) Anthracite (hard coal),
- (b) Bituminous (soft coal),
- (c) Lignite (brown coal).

4.2. Anthracite coal is mined in Pennsylvania, Rhode Island, and Arkansas.

4.3. There are 23 districts in the United States which mine bituminous coal.

4.4 Anthracite is less smoky and gives off less sulfur dioxide, but it is not as abundant as bituminous.

4.5. After coal is mined, it is generally prepared before it is used. Raw or unprepared coal is used in some power plants--mine mouth plants. Preparation of coal includes crushing and cleaning to remove impurities, drying to remove moisture, and separation into the desired sizes.

4.6. Two basic methods are normally used to describe the composition of coal: the Proximate Analysis and the Ultimate Analysis.

4.7. Proximate Analysis gives the percentages by weight of the following which are found in the coal:

- (a) Volatile Matter - portion of the coal that will form gases and vapors (hydrocarbons,

hydrogen, and carbon monoxide)

and are driven off when the coal sample is heated in a covered crucible at 1740°F for 7 minutes.

(b) Fixed Carbon - solid portion

that is left when volatile matter is distilled off. It is mostly carbon, burns slowly, and will give a bluish flame.

(c) Ash - portion that will not

burn. Slate, clay, sandstone, shale, carbonates, pyrite, and gypsum.

(d) Moisture Content.

The sulfur content in percent and the heat content in British thermal units per pound (Btu/lb) are generally also given, although they are not part of the analysis. This Proximate Analysis may be made on the coal as received (AR) or dry (excluding the moisture).

4.8. The Ultimate Analysis gives the chemical composition of the coal by dividing the coal, except for the ash, into its basic elements.

4.9. In the Ultimate Analysis the volatile matter and fixed carbon of the Proximate Analysis are divided into their chemical components--hydrogen, carbon, oxygen, and nitrogen.

4.10. Another measurement which describes the coal is the Screen Analysis, or Size Distribution. It tells the percentage of the coal that will fall through a screen with a certain size opening but which will not fall through the next smaller size screen.

4.11. The Screen Analysis can be made with a screen having either round or square holes, but the two screens will give different totals. Thus, the type of holes should be specified.

4.12. Coal sizing terms:

Run of mine - unscreened broken coal
from the mine

Slack - all the coal passing through a
screen of a given size, such as
3/4" slack.

Double-screened sizes such as "egg,"
"stove," "nut," "pea," and "stoker" -
trade names in bituminous coal that
are standard sizes for anthracite.

4.13. From the air pollution viewpoint, the amounts of volatile matter, ash, and sulfur, along with the heating value, are the most important part of the Proximate Analysis. Volatile matter is related to the emission of smoke; ash is related to particulate emission. Sulfur content is related to sulfur oxide emissions. Heating value is related to the total amount of pollutant production.

4.14. The size of the coal is important to the smoke and flue dust emission. The optimum coal size is determined by the method of firing.

4.15. The impurities in coal are ash, moisture, and sulfur.

4.16. The ash is dispersed throughout the coal as finely divided matter or is present as pieces of slate, rock or clay. The pieces of ash can be removed in preparation plants by crushing and washing.

4.17. Power plants usually burn higher ash coals, while lower ash coals go to the retail market.

4.18. Moisture may be present as finely divided amounts of water dispersed throughout the coal or as water clinging to the coal surface. A certain amount of moisture is helpful in reducing the tendency of coal to form strong coke in some stokers. It also prevents a dust problem.

4.19. Sulfur is found in coal in three forms:

- (a) As an iron disulfide, FeS_2 , called pyritic sulfur or as golden-colored iron pyrites in the form of very heavy balls or lenses and in small flakes or crystals or bands as partings. This sometimes is called "Fools Gold."
- (b) Organic sulfur originating with and forming an inherent part of the plant life that formed the coal.
- (c) Combined sulfur, generally a sulfate with calcium or other mineral matter and seen as a gypsum with a white surface or as veins in the coal.

High-sulfur coal is characterized by the fact that content of all three forms of sulfur is high. Very often with high-sulfur coal, the pyritic form will be as prevalent or more so than the organic and sulfate forms combined.

4.20. The pyritic sulfur is found in small discrete particles within the coal; a percentage of this sulfur may be removed by washing or other mechanical means. However, even after washing, most of the pyritic sulfur and all of the organic sulfur will remain in the coal.

4.21. At present, no economical means is in general use for the removal of any of the organic or sulfate forms of sulfur from the coal prior to its initial use.

Basics of Coal Combustion and Combustion Equipment

4.22. Some of the terminology describing characteristics of most coal-burning furnace systems are as follows:

- (a) Fuel bed - layers of coal distributed over a grate which allows the air to move through the coal layers.
- (b) Stoker for feeding fuel - by which coal can be added to the bed from above (overfeed) or below (underfeed).
- (c) Air - which can be introduced beneath the coal burning on the fuel bed (underfire air) or above it (overfire air).
- (d) Arch - the portion of the combustion chamber above the fire; it is constructed of material capable of withstanding high temperatures (refractory material) and is of a design that will reflect the heat back into the fire.
- (e) Heat-exchange equipment - converts the heat released by the coal into a form that can be used; frequently, the heat exchange is accomplished by placing metal tubes at the exit of the combustion chamber and converting the water in these tubes to steam.

(f) Breeching - originally, the connecting link between the furnace and the chimney; currently, one may expect to find one or more of the following between the same two points: (1) economizer, (2) air preheater, (3) fly-ash collector (mechanical and/or electrical), and (4) induced draft fan. In effect, the breeching thus becomes a series of short duct-work connectors.

(g) Chimney - transports the waste products of combustion out into the air for disposal by dispersion.

4.23. Coal will not burn as a solid; no fuel will. The combustion process must vaporize, gasify, or break down a solid into individual molecules by the addition of heat.

4.24. When coal is burned on grates, one of two types of feeding mechanisms is generally used--underfeed or overfeed.

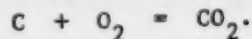
4.25. The underfeed operation introduces the primary air and the fuel from below the grate. The fuel burns from the top to the bottom of the bed.

4.26. Overfeed operation introduces coal to the grate from the top and the primary air from below. Burning occurs from the bottom to the top of the fuel bed.

4.27. When coal burns in an overfeed bed on a grate, the process takes place in layers:

(a) At the bottom of the bed and above the grate where a layer of ash serves to protect the grate and preheat the primary air.

- (b) The "oxidation zone," where, as the air temperature rises, the heat vaporizes the volatile and carbonaceous material from the coal particles and removes this material. In this vaporous state the combustible material burns in the reaction:



This is the hottest part of the fuel bed.

- (c) The "reduction zone," where, because of the lack of oxygen, the carbon dioxide combines with the volatilized carbon forming carbon monoxide.
- (d) The top layer, where the volatile hydrocarbons and tars are driven off the fresh coal.

4.28. Unless more air (secondary air) is introduced, the hydrocarbons and tars crack, decompose, or condense and are emitted to the atmosphere as white, yellow, or black smoke. If oxygen is present in sufficient quantity at the time the volatile matter is distilled, the hydrocarbons oxidize completely without forming soot and smoke through the thermal cracking and condensation reactions. Secondary air is sometimes called combustion air and, since it is introduced above the fire, it is often identical to "overfire air."

4.29. Overfeed fuel beds are smoky because burning gases rise through fresh fuel, thus resulting in rapid devolatilization of the fresh fuel in a zone having a deficiency of oxygen.

4.20. Underfeed beds are inherently smoke free. The air and fresh fuel flow upward together. The zone of ignition, which is near the point of maximum evolution of the combustible gases, is supplied with ample well-mixed air which promotes complete combustion.

4.31. Heat-exchange equipment converts the heat released by the burning of the coal into a form that can be used. There are five categories:

- (a) Radiant heat absorbers - can line furnace walls with watercooled surfaces. These surfaces transmit to the water the heat which is radiated to them.
- (b) Boilers or convection heat exchangers - the earliest boilers were tanks containing water under which a fire was built. Next, the heated gases from the furnace were directed around the water tank and through a large tube which passed through the tank. Next, this return tube was replaced by many small tubes (3 or 4-in. ID). There are three types of boilers in use currently:

- (1) Fire-tube boiler - fire is made in the large tube and the gases make several passes through the smaller tubes.
- (2) "Fire-box" boiler - gases flow from the furnace through tubes, then reverse and flow through more tubes to the stack.

- (3) Water-tube boiler -
water goes from a drum
through several straight
tubes to another drum.
- (c) Superheaters or gas-to-vapor heat
exchangers.
- (d) Economizers or added-convection
heat exchangers.
- (e) Air preheaters or gas-to-gas heat
exchangers.

Some Terms Used in
Coal Combustion

4.32. Draft is a measure of the positive pressure or negative pressure (vacuum) or air or gases in various parts of a combustion system. There are several types of draft:

- (a) Forced draft - air pressure is supplied by a fan pushing air into the system.
- (b) Induced draft - a negative pressure is created by pulling air out of the system with a fan.
- (c) Natural draft - suction in the system is created when the flue gases expand and go up the stack. This causes primary air to be drawn into the furnace system to balance out the negative pressure.
- (d) Furnace draft - the pressure of the gases in the furnace is positive or negative.

If it is positive, the gases will leak out of the furnace. If it is negative, gases will leak in.

- (e) Draft losses - pressure losses occur as the flue gas flows through the combustion system.

In principle, both natural and induced drafts are akin in that they both function from the exhaust or discharge end of the furnace system. Forced draft functions from the opposite or feed end of the system.

4.33. Coke is the fixed carbon and ash which are left after the coal has been heated and the volatile matter has been driven off. Coking coal refers to a coal that melts and fuses to form larger lumps, even though the coal may have been in small pieces. Bituminous is usually a good coking coal and anthracite is not.

4.34. Carbon in the ash - if some of the coal is heated enough to drive off the volatile matter but does not finish burning all of the carbon, the ash will contain some pieces of unburned carbon or coke.

4.35. Overfire air - air is injected above the fuel bed instead of through it as is normal. The overfire air is forced through jets or nozzles in the furnace walls. The purpose of the overfire air jets is to increase the mixing or turbulence of the gases to insure complete combustion and prevent smoke.

4.36. Slagging - when molten ash particles build up on the walls or tubes of a boiler and flow together, the deposit is called slag and the process is called slagging.

Plume Visibility

4.37. The visible plume from coal combustion may be caused by condensed water vapor, sulfur trioxide/sulfuric acid mist, organic liquids or solids, particulates, and smoke.

- (a) Water vapor condenses and produces a white plume which dissipates rapidly.
- (b) Sulfur trioxide and sulfuric acid mist cause a detached bluish-white plume that does not dissipate readily.
- (c) Organic liquids and solids cause a white, yellow, or brown plume.
- (d) Particulates (including fly ash) cause the plume to be white, brown, or black.

4.38. Smoke - the black clouds called smoke are actually small, unburned or partially burned solid carbon particles and solid or liquid hydrocarbon particles. They result from the incomplete combustion of the volatile products of the fuel. The carbon of the smoke does not arise from the free carbon of the fuel but from the cooling of the hot hydrocarbon gases of the volatile matter. If these particles are deposited inside the combustion system, they are called soot.

4.39. Once formed, carbon soot is difficult to burn. To prevent this soot from being carried away as pollution, the hydrocarbons should be burned as close as possible to the fuel bed before they are decomposed by the heat into soot and smoke.

4.40. It has been found that there is a marked rise in the percentage of both carbon (soot) and tar (benzene soluble) contained in the particulate as the smoke density increases.

4.41. The black smoke plume is visible because of the size of its solid and liquid particles. They range between 0.01 and 2.0 microns in diameter, but most are between 0.3 and 0.6 micron, a size which is highly effective in scattering or absorbing light.

4.42. These particles between 0.3 and 0.6 micron in diameter contribute little to the mass of the emissions. Most of the mass is in the larger particles, which have little effect in absorbing or scattering light.

4.43. The black shade of a combustion plume can be reduced by a good adjustment of air-to-fuel ratio. One indication of this is the flame in the furnace:

- (a) With a good adjustment of air to the coal feed, the flame will be yellowish orange in color with no black tips. It will appear soft. And its luminosity will give a maximum of radiant heat-energy transfer.
- (b) If the air is increased, the flame will become whiter in color and will appear to be harder, sharper, and more erosive. Its radiant heat energy will be lessened.
- (c) If the air is decreased too much, the flame will be blacker and will appear lazy and without life. Since a reducing atmosphere is now well indicated, soot may be formed and collect at some point in the system. The smoke will be dark.

- (d) When complete burning of coal is accomplished, visible emissions will range from zero to a light tan or gray haze depending on the ash content of the fuel and the efficiency of the emission control equipment.

4.44. When a flame impinges on a cold surface, smoke and soot are formed. Complete combustion should be obtained before the flame is allowed to hit a cold surface.

Mechanical Coal-Firing Equipment

4.45. Overfeed stokers - earliest type consisted of a steeply inclined grate with alternate stationary and movable sections. Coal moved down the grate when a lever outside the furnace was moved.

4.46. Underfeed stokers - two forms: single retort and multiple retort.

4.47. Single retort - consists of coal hopper, one feed trough or retort containing a feeding device (a screw or pusher) with the grate above it. This stoker moves coal (a) from front to rear in retort, (b) from retort upward to the grate where it is burned, (c) sideways on the grate to the ash pits at the sides. Widely used with smaller boilers.

4.48. Multiple retort - early variety had one coal hopper across several parallel retorts. Ash was dumped periodically from the rear into an ash pit. Later, all the retorts were driven by a single crankshaft. They require forced draft fans. There may be as many as 18 multiple retorts.

4.49. Traveling grate stoker - grate surface consists of an endless belt with sprockets at either end. Coal hopper with a grate at one end controls the coal feed. Grate is moved with gears powered by an electric motor or turbine. Coal is laid on the grate from the hopper and is moved through the furnace as the burning takes place. Ash is dropped off the grate into an ash pit at the rear. Presently forced-draft fans are used with traveling grate stokers.

4.50. Vibrating grate stoker - consists of a water-cooled grate structure on which the coal moves from the hopper at the front of the boiler through the burning zone by means of a high-speed vibrating mechanism. As with the traveling grate, the fuel bed progresses to the rear, where the ash is continuously discharged. Vibrating stokers may emit slightly higher concentrations of fly ash than traveling-grate stokers because of increased agitation of the fuel bed.

4.51. Spreader stoker - consists of a coal hopper, a feeding mechanism, and a device that injects the coal into the furnace (usually a rotating flipper). The coal is thrown into the furnace and partly burned in suspension. The larger particles fall to the grate and burn there. Essentially, the spreader stoker employs overfeed burning, an inherently smokey method, plus suspension burning, an inherently smoke-free method producing fly ash. Overfire jets have been found essential to smoke-free operation. They also reduce dust emission significantly, but not enough to meet most ordinances, unless a particulate collector is used.

4.52. Pulverized-fuel firing unit - in this system, coal is pulverized to particles, at least 70 percent of which pass through a 200-mesh sieve (median size of the particles is 5.0 microns). In direct-firing systems, raw coal is dried and pulverized simultaneously in a mill and is fed to the burners as required by the furnace load. A predetermined coal-air ratio is maintained for any load. In indirect-firing systems there are storage bins and feeders between the pulverizers and burners. Pulverized-fuel firing units are of two basic types--wet bottom and dry bottom. In a wet-bottom unit, the temperature in the furnace is maintained high enough so that the slag does not solidify (or fuse) and it can be removed from the bottom as a liquid. The dry-bottom furnace maintains a temperature below this point so that the ash will not fuse. The steam electric plants, where pulverized fuel firing is used most, emit 50-80 percent of the ash fired in the coal as fine fly ash. Therefore, all modern plants of this type must have high-efficiency dust collectors.

4.53. Cyclone furnace - fires crushed coal that is nearly as fine as pulverized coal into a water-cooled, refractory-lined cylindrical chamber 8 to 10 feet in diameter. The coal and air swirl in a cyclonic manner as the burning proceeds. Combustion is so intense that a small portion of the molten ash coating the wall of the chamber is vaporized. Approximately 85 percent of the ash fired is retained as molten slag; hence, the fly-ash load is much lower than with pulverized coal. However, the ash which does escape the cyclone is extremely fine and thus difficult to collect.

4.54. Pulverized-coal burners and cyclone furnaces are the universal equipment for firing coal in the large new electric-generating stations.

4.55. Some types of burning equipment (underfeed stokers, overfeed stokers, spreader stokers, and pulverized-fuel burners) make use of a certain amount of fly-ash reinjection. In this process, cinders are returned to the grate from the fly-ash collector and burned again to reduce the loss of unburned carbon. The usefulness of this method is limited, for whenever the fly ash is reinjected pneumatically, the total fly ash from the unit is eventually increased.

Causes and Control of Particulate Emissions From Coal Combustion

4.56. Emissions of smoke and particulates may be caused by the type of coal, the type of combustion equipment, or improper combustion.

4.57. Improper combustion - if a furnace produces smoke, either the fuel and air are not in balance or the three T's of combustion are not being satisfied. The cause may be one or more of the following conditions:

- (a) Insufficient air for the amount of fuel;
- (b) Improper distribution of the air or fuel;
- (c) Too much air (usually overfire air), which chills the flame before all combustion is complete;
- (d) Insufficient turbulence or mixing of the air;
- (e) Cold fire box - often caused by excessive furnace draft, which pulls outside air into the fire box through doors and leaks; it usually occurs at low load.

4.58. Possible causes for improper distribution of air or fuel:

- (a) Uneven depth of fuel bed,
- (b) Plugged air holes in the grate,
- (c) Clinker which shuts off air flow,
- (d) Leaky seals around the edges of the grate area,
- (e) Improper burner adjustment.

4.59. Possible reasons for insufficient turbulence:

- (a) Insufficient overfire air,
- (b) Plugged overfire air nozzles,
- (c) Nozzles that are improperly aimed,
- (d) Incorrect burner adjustment,
- (e) Excessive furnace draft.

4.60. Importance of coal and equipment in particulate emissions:

- (a) Type of firing - least emission occurs with underfeed stokers, the greatest with pulverized coal.
- (b) Furnace design - least emission with large furnaces and greatest with small furnaces of pulverized coal furnaces.
- (c) Secondary air jets tend to reduce emission.
- (d) Coal size - the greater the proportion of small sizes, the greater the emissions. Smaller sizes are more easily swept up the chimney.

- (e) Volatile content - high-volatile coal results in a long, opaque flame that is more likely to strike the cooler surfaces of the furnace resulting in soot formation. Low-volatile fuel burns with a short, transparent flame.
- (f) Amount of ash - the higher the ash content, the greater the emission of fly-ash.
- (g) Fly-ash reinjection - if fly ash is reinjected, there can be an accumulation in the furnace of suspended solids formed from the combustible portion of the coal.
- (h) Firing rate - as the firing rate increases, the velocity of the gases passing through the furnace increases. And as the velocity increases, more and larger particles are carried out of the furnace.

4.61. The most important variable in hand-fired furnaces is the volatile content of the fuel burned, the smoke potential increasing rapidly as volatile content increases.

4.62. Several types of control equipment have been used to collect the particulates from coal combustion:

- (a) Settling chambers,
- (b) Large-diameter cyclones,
- (c) Multiple small-diameter cyclones,
- (d) Wet scrubbers,

(e) Electrostatic precipitators,

(f) Fabric Filters (in limited use as of 1977).

4.63. The settling chamber is a low-efficiency, low-cost, low-pressure-drop device. It generally is applied to natural-draft, stoker-fired units. Collection efficiency is 50 to 60 percent.

4.64. Large diameter cyclones have lower efficiency and lower pressure drops than smaller diameter cyclones. Their efficiency ranges from 65 percent for stoker-fired units to 20 percent for cyclone furnaces.

4.65. Multiple small-diameter cyclone units are used as precleaners for electrostatic precipitators or as final cleaners. Efficiencies range from 90 percent for stoker-fired units to 70 percent for cyclone furnaces.

4.66. Wet scrubbers are limited to the control of particulate emissions during soot blowing, although alkaline scrubbers to remove both fly ash and sulfur dioxide are also used.

4.67. Electrostatic precipitators are the most commonly used devices for cleaning the gases from large, stationary combustion sources such as those burning pulverized coal. They are capable of efficiencies of 99 percent or more.

4.68. Efficiency of collection for cyclone collectors increases as the load increases. An increase in the carbon content of coal is usually associated with an increase in size distribution. Thus, as firing rate increases or the carbon content of the coal increases, the centrifugal collector becomes more efficient.

4.69. The electrostatic precipitator becomes less efficient as the load increases. An increase in carbon content is associated with an increase in electrical resistivity. Electrostatic precipitators are not generally used for high-carbon ash, which is derived from stockers. They are best adapted to pulverized coal-fired and cyclone-fired units.

Suggested Additional Reading

Atmospheric Emissions From Coal Combustion, W. S. Smith and C. W. Cruber, DHEW, PHS Publication No. 999-AP-24, (1966). Available through National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

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CHAPTER V.

OTHER COMBUSTION EMISSIONS: INCINERATORS, AGRICULTURAL BURNING, NATURAL GAS AND MOBILE SOURCES

The combustion of coal and fuel oil in stationary sources produces a large number of visible plumes. More efficient combustion of these fuels can reduce the opacity of the plumes produced from these sources. Other types of combustion, both for the production of usable energy and for the burning of waste materials, will produce black and non-black plumes. Some of these combustion sources and the cause and control of their plumes are discussed in this section.

Solid Waste Disposal by Incineration

5.1 The methods of burning solid waste include the use of open-top or trench incinerators, conical metal ("tepee") burners, domestic incinerators, apartment-house incinerators, and municipal incinerators as well as open burning.

5.2 Incinerators can be classified in several ways, such as by their size, their method of feeding, the type of waste they will handle, or the number of combustion chambers they contain.

5.3 A single-chamber incinerator is designed so that feeding, combustion, and exhaust to a stack take place in one chamber.

5.4 The multiple-chamber incinerator has three or more separate chambers in series for admission and combustion

of the solid refuse, mixing and further combustion of the fly ash and gaseous emissions, and settling and collecting of the fly ash.

5.5. Multiple-chamber incinerators are of two general types:

- (a) Retort, in which the ignition chamber, mixing chamber, and combustion chamber are arranged in a "U".
- (b) In-line, in which the three chambers follow each other in a line.

5.6. The tepee burner has been used by the lumber industry to incinerate wood wastes and by some small cities to dispose of municipal refuse. These burners range from 10 to 100 feet in height. They are single-chamber incinerators and are not designed to minimize atmospheric emissions; thus, they rarely meet visible emission regulations when in use and have considerable fly-ash fallout.

5.7. The tepee burner may be fed by a bulldozer, a dump truck, or a conveyor. Feeding with bulldozers or trucks requires that the doors at the base of the burner be opened. This stops the motion of the draft air inside the burner and cools the combustion gases. The dumping of the charge on the burning pile smothers the fire. All of these factors contribute to incomplete combustion and additional smoke.

5.8. Domestic incinerators may range from units such as a single-chamber backyard wire basket to dual-chamber incinerators having a primary burner section followed by an afterburner section. Many air pollution control agencies have banned backyard incinerators and some have banned all types of domestic incinerators.

5.9. The emissions of smoke and fly ash from apartment-house incinerators are often high because of low combustion temperatures, improper air regulation, and poor operating and maintenance practices.

5.10. Apartment-house incinerators may be of two types--flue-fed and chute-fed. In the single chamber-flue-fed unit, refuse is charged down the same passage that the products of combustion use to leave the unit. Refuse dropped onto the fuel bed during burning smothers the fire, causing incomplete combustion and emission of smoke. Unless controlled by an approved type of after-burner or other equivalent device, the flue-fed and chute-fed incinerator emissions will exceed emission standards.

5.11. A chute-fed multiple-chamber incinerator has separate passages for refuse charging and combustion-product emission. Nevertheless, the emissions from this incinerator often exceed emission standards. One cause is the high natural draft in the flues of the tall stacks that go to the top of the apartment house. This high draft carries with it a large amount of particulates and fly ash. A barometric damper will alleviate the high draft.

5.12. Single-chamber incinerators used for commercial or industrial establishments have been largely replaced by multiple-chamber types. They may handle from 50 to several thousand pounds of refuse per hour.

5.13. The average capacity of municipal incinerators is 300 tons of refuse per day. They may be fed in batches or continuously. Continuous-feed units are preferable, because operating parameters--such as combustion-chamber temperatures that affect particulate emissions--can be closely controlled.

5.14. The gases leaving an incinerator may have temperatures as high as 1800°F, which is much higher than the 600°F, maximum for steam-generating boilers. The higher temperatures mean a higher plume rise but also a greater volume of gas and more expensive breechings, chimney linings, and air pollution control equipment.

5.15. Some rules that should be met by any incinerator to minimize the particulate emissions are as follows:

- (a) Air and fuel must be in proper proportion and mixed adequately.
- (b) Temperature must be sufficient for combustion of both solid fuel and gaseous products.
- (c) Furnace volume must be large enough to provide adequate time for complete burning of the combustible materials.

NOTE - these rules are a restatement of the "three T's of combustion."

5.16. Some operating practices that can help to reduce the smoke from incinerators include the following:

- (a) On a cold start, feed nonsmoky material slowly and increase the frequency of the charge--not its size--until the secondary combustion chambers get hot.
- (b) If smoke is a problem, keep the charging opening practically blocked with waste.
- (c) It is often an advantage to mix slow-burning material with flash-burning material. This can be done to achieve more efficient incineration of wet garbage or it can be done to reduce smoke by mixing smoky materials, such as plastics and rubber, with paper waste.

(d) Excessive fly ash is usually the result of too great a draft. The draft can frequently be reduced by partially closing the damper, which is installed in the breeching between the furnace and the stack.

5.17. Dark smoke from incinerators consists primarily of small carbon particles resulting from incomplete combustion. The dark smoke may mask the light-colored plumes also emitted from the incinerator.

5.18. Light-colored plumes are emitted from most municipal incinerators. These plumes are caused by volatilization of particles or by chemical reactions in the fuel bed. Analysis of the plume shows appreciable quantities of metallic salts and oxides in microcrystalline form which were transformed into the vapor state in the fuel bed and then condensed. Removal of these very small particles from the flue gases is difficult. The equivalent opacity of the plume can be partially reduced by proper incinerator design.

5.19. Large fly-ash particles may be either charred material or incombustible particles. If complete combustion is achieved, there should be no charred particles. The incombustible material may come from chemical reactions in the fuel bed. It may also be from small particles that were present in the refuse.

5.20. The size of the particles formed by chemical reactions may range from submicron to 10-micron diameters. Much of the weight of the particulate matter is in the particles greater than 5 microns. These can be removed from the combustion emissions by collecting devices.

5.21. Several types of collection devices which have been used with incinerators and their efficiencies

(by total weight of all particles without regard to size) are given in the following tabulation:

<u>Collection Device</u>	<u>Collection Efficiency, percent</u>
Settling chamber	10-35
Wetted baffle-spray system	10-55
Cyclones and multiple cyclones	60-80
Wet scrubbers	94-96
Electrostatic precipitators	96-99+
Bag filters	99+

The use of bag filters for incinerators is very limited. Their utilization depends on considerations of temperatures and moisture content of the gas stream as well as the pressure drop across the filter.

5.22. The per capita quantity of solid waste generated in the United States has been increasing in recent years. The physical and chemical properties of the garbage have also been changing. Moisture content has been decreasing with diminishing household garbage. As a consequence of the decreasing use of coal for home heating, there are less ashes for disposal. The combustible content and the heat value of the solid waste have been increasing, principally because of the greater use of paper and plastics.

5.23. In a study of incineration of tepee burners, several observations were made regarding the density of smoke produced when different types of material were burned:

- (a) Plastic products (polyvinyl chloride, etc.), rubber products, and asphalt products (tar paper, linoleum tar blocks, etc.) produced Ringelmann No. 5 or 100 percent equivalent opacity smoke.

- (b) Leather products produced copious quantities of Ringelmann No. 5 smoke lasting hundreds of yards downwind.
- (c) Ashes from home use produced Ringelmann No. 3 to 4 smoke.
- (d) If the refuse contained garbage of more than 15 to 20 percent by weight and if this garbage was not mixed uniformly with dry refuse, smoke emissions of No. 4 to 5 Ringelmann generally occurred.
- (e) If the charge contained more than 30 percent damp material even when mixed with dry combustible material, the pile tended to smolder, producing an undesirably large amount of smoke. Furthermore, the buildup of a large pile of charged refuse cut down on the draft through the pile and contributed to additional incomplete combustion.

The study recommended that plastic, rubber, asphalt, and leather products not be burned in tepee burners.

Agricultural Burning

5.24. Open burning of several kinds is done in connection with agriculture. The burning is done for waste disposal, for disease pest control, and as part of harvesting or land management. All of these types of burning will result in visible smoke and other air pollution effects such as visibility reduction, fallout of carbonaceous residues, contributions to photochemical smog, and odors.

5.25. For some of this burning, there is a flexibility in the time when the burning can be done and in the area that can be burned during any one fire. In these

cases, the burning should be scheduled for periods when meteorological conditions such as wind speed and inversion height are conducive to good dispersion of the smoke. However, the winds cannot be too strong or there may be a chance of the fire getting out of hand.

5.26. Burning of this type includes the cleaning out of weeds and brush when chemical methods are undersirable, the removal of the slash remaining after logging operations, the clearing of potato vines, peanut vines, and sugarcane leaves prior to harvest.

5.27. Other agricultural burning cannot be scheduled. One example is the burning of smudge pots in orchards to reduce the hazard from frost. Another is disposal of cattle affected by hoof and mouth disease at a time of the year when burial is not possible because of frozen ground or other reasons.

5.28. Other agricultural burning includes the burning of field crops such as barley and rice, the removal of prunings from fruit and nut trees, the incineration of brush, and the burning of cotton gin waste to aid in the control of bollworms.

5.29. The density of the smoke from agricultural burning will depend upon the combustion temperature and the residence time of the fuel at that temperature. If the moisture content of the fuel is high, the smoke will be of a white shade indicating the presence of water vapor. The greener the plant life, the more moisture it contains and the whiter the smoke will be.

Combustion of Natural Gas

5.30. The particulate emissions from the normal combustion of natural gas are insignificant compared with

those from coal and oil. Control equipment is not utilized to control the emission from natural gas combustion equipment.

5.31. Natural gas constituents normally includes methane (CH_4), ethane (C_2H_6) in varying proportions, and lesser amounts of nitrogen (N_2) and carbon dioxide (CO_2).

5.32. The table compares the chemical composition of typical samples of coal, fuel oil, and natural gas:

	Content, percent		
	Coal	Oil	Gas
Hydrogen	5	10	24
Carbon	78	86	75
Sulfur	3	3	trace
N_2 , O_2 , etc.	7	0.6	1
Ash	7	0.4	-
	100	100	100

5.33. One should note the high percentage of hydrogen in natural gas. This high percentage results in a large amount of water vapor being present in the gases exhausted from combustion. As a consequence, the plume from natural gas combustion under certain ambient temperature and moisture conditions can be a very dense white plume of condensed water vapor.

5.34. The water produced in combustion will absorb 900 Btu's in changing from the liquid to the vapor state. Thus, fuels containing more hydrogen provide less available heat than fuels containing small amounts of hydrogen.

5.35. In heat-generating installations, one of the principal components is the heat exchanger. The heat exchanger contains the medium, such as water, that is to be heated, and its outside surface area is exposed

to the hot gases generated by the burning fuel. Boilers are rated on the total area of heating surface of their heat exchangers.

5.36. Burners can be divided into two broad classifications - atmospheric and mechanical draft.

5.37. The atmospheric burner depends entirely upon the negative pressure within the furnace to draw combustion air through the burner assembly. Natural draft can be created by a stack. Theoretically, the draft is proportional to the difference between the stack temperature and ambient temperature and to the height of the stack.

5.38. The mechanical draft burner depends upon a blower (usually, a forced-draft blower--not an induced-draft blower) to supply the combustion air to the burner. With this type of burner a low-profile building with a short "stub" stack can be used to house the boiler.

5.39. Smoke from the stack of a natural gas installation is evidence of improper operation of the gas burner, specifically, that there is insufficient combustion air.

5.40. Other indications of insufficient air will be

- (a) A burner flame that is extremely rich, having an orange-red appearance;
- (b) Soot deposits on heat-exchanger surfaces;
- (c) Burner pulsation;
- (d) Excessive gas consumption.

5.41. One of the common reasons for insufficient combustion air--one that is frequently overlooked--is the lack of adequate fresh air opening into the boiler room. There must be some permanent provision (not just an open window) to ensure that fresh air will always be supplied to the combustion equipment. One of the first

indications of an inadequate air supply is a hot, stuffy feeling in the boiler room.

Engines Used in Transportation

5.42. There are three engines commonly used in the United States to propel surface vehicles and aircraft. These are the spark-ignited internal combustion engine, the compression ignited internal combustion engine, which is frequently referred to as the diesel, and the aircraft gas-turbine engine.

5.43. The first of these is used in automobiles, light-duty trucks, light aircraft, motorcycles, outboard motors, and small gasoline utility engines.

5.44. The diesel engine is used in large trucks, buses, locomotives, ships, and heavy construction equipment.

5.45. The gas-turbine engine is commonly used on large aircraft.

5.46. Both types of internal combustion engines can be subdivided into four-stroke-cycle engines. These two operating cycles differ in the number of times the piston rises in the cylinder during the combustion of the fuel in the cylinder. Both cycles consist of four parts. The operations that take place in the spark-ignition engine during the four parts of the cycles are:

- (a) Intake of air and fuel;
- (b) Compression of fuel-air mixture during which ignition of the mixture is set off by the spark from a spark plug;
- (c) Expansion of the burning mixture, forcing down the piston and delivering the power which drives the vehicle;
- (d) Exhaust of the burned gases out of the cylinder.

5.47. The differences between the gasoline and diesel engines are the method of ignition and the fuel systems. In the diesel engine the fuel does not enter the cylinder as a mixture with the air but is injected into the cylinder through nozzles during the phase when the air is being compressed to a high pressure and high temperature. Fuel injected into this high-temperature air ignites without a spark.

5.48. The aircraft gas turbine consists of four main sections: a compressor, a combustion chamber or combustor, a turbine, and a tailpipe.

5.49. When a plane is moving, air is forced into the front of the engine where the compressor is. The compressor, a multibladed fan, compresses the air to several times its density, increasing its temperature and pressure.

5.50. The compressed air then passes into the combustors, into which fuel is sprayed. The mixture of fuel and air is ignited producing a high-temperature exhaust gas.

5.51. This exhaust gas is expanded into the turbine. The expansion drives the turbine, giving it sufficient power to rotate the compressor blades.

5.52. After passing through the turbine, the exhaust gas may still have enough velocity to provide a backward push against the outside air helping to thrust the aircraft forward.

5.53. There are three categories of aircraft gas-turbine engines: turbojet, turboprop, and turbofan.

5.54. The turbojet engine uses a great proportion of the energy of the turbine exhaust gases to provide thrust for the aircraft. This is done by designing a suitable exit nozzle. Turbojet engines perform best at high altitudes and high speeds.

5.55. Turboprop engines have a propeller mounted in front of the compressor. They are designed so that most of the energy of the expanding exhaust gases is used in turning the turbine and subsequently to rotate the propeller. These engines operate best at low altitudes.

5.56. In the turbofan engine the fans of the first stages are larger in diameter than the others. The air taken into the center portion of the compressor passes through as with the turbojet engine. The exhaust gases turn the turbine, driving the compressor, and expand out the rear of the engine producing additional jet thrust. Because of the increased frontal area of this engine, it is better adapted to subsonic than to supersonic flight.

Visible Emissions From Mobile Sources

5.57. Particulate matter is emitted from a gasoline engine in the exhaust gases and in the blowby gases, which escape past the piston rings into the crankcase and then into the exhaust.

5.58. Carbon, metallic ash, and hydrocarbons in aerosol form are the principal particulate emissions. If an automobile is performing properly these particles will essentially all be less than 5 microns in size and visible smoke will not occur.

5.59. The color of smoky exhausts may be blue, black, or white. Blue and black smoke are indicators that the engine needs repair.

5.60. White smoke results from the condensation of water vapor in the exhaust. There is always water vapor produced in the combustion of gasoline. White smoke from an exhaust will be more likely during cold

weather when the vapor is cooled to the visible liquid state. The white smoke will be more noticeable on moist days when the air is saturated so that the wet plume cannot evaporate and when an automobile is standing still so the plume is not dispersed by the motion of air.

5.61. If the exhaust smoke has a bluish tinge, oil is leaking into the combustion chamber of the engine and is being burned there with the gasoline.

5.62. Oil can enter the combustion chamber in three ways: through a cracked vacuum pump diaphragm, through an excessive clearance around the intake valve, and between the piston rings and the cylinder walls. The latter entry may be due to worn cylinder walls or to worn or carboned rings.

5.63. Black exhaust smoke is composed of unburned gasoline. This indicates that the fuel-to-air mixture is excessively rich in fuel.

5.64. Some causes of black smoke from a gasoline engine are

- (a) Excessive fuel pump pressure or pump leakage;
- (b) Choke not opening properly;
- (c) Clogged air cleaner
- (d) Carburetor in need of repair or adjustment;
- (e) Faulty spark plugs which cause the engine to "miss" and not use all the fuel.

5.65. The California Motor Vehicle Code in essence states that no motor vehicle first sold or registered after January 1, 1971 shall discharge into the atmosphere for a period of more than 10 seconds any contaminant equal to or exceeding 20 percent opacity. Forty percent opacity applies to vehicles before this date.

5.66. Particulate matter emitted by diesel engines consists primarily of carbon and hydrocarbon aerosols, which result from incomplete combustion of the fuel. Diesel exhaust is made up of particles of which 62.5 percent are less than 5 microns in diameter and 37.5 percent are from 5 to 20 microns.

5.67. Maximum emissions of visible smoke from diesel engines occur during full-throttle acceleration and during deceleration or "lugdown," also at full throttle. At full or open throttle the fuel-to-air ratio is enriched. This fuel-rich mixture is desirable during acceleration because it provides greater power. The greater power is achieved at the expense of fuel economy.

5.68. The power of the diesel engine is controlled by the amount of fuel injected into the combustion chamber through nozzles during the compression phase of the engine cycle.

5.69. If the fuel system is kept at the setting prescribed by the manufacturer, the smoke emissions should meet established standards. As vehicle mileage increases, low levels of visible emission can be maintained by proper fuel system adjustment, maintenance at appropriate intervals, use of specified type of fuel, and good operating techniques. Maintenance will correct dirty or eroded injection nozzles, which can occur even in a properly adjusted engine.

5.70. It has been found that truck operators sometimes increase the horsepower of their engines by altering the fuel-injection setting prescribed by the manufacturer. By this means the operator can install an engine which is underrated for the load required and then meet the power requirement by overfueling. However, this increase

in power also raises the level of black smoke.

5.71. Most turbine engines in nonmilitary aircraft use aviation kerosene as a fuel. The turbine engines operate at fuel-to-air ratios five to twenty times less than those used by piston engines. During flight the emissions of particulates are low. However during the takeoff and landing operations, the engines operate under high fuel-to-air ration conditions and visible smoke is emitted. The quantity of the solid material released is small, but is highly visible.

5.72. Particulate matter originates near the upstream end of the combustor, where fuel is injected and where the fuel-rich regions are. Alteration programs for replacing smoking engines involve the replacement of conventional combustors (or burner cans) with new smokeless burner cans.

5.73. A series of tests on different kinds of conventional aircraft turbine engines has been run to determine the density of the smoke emitted under different power settings including idle, takeoff, climb-out and approach power. The results are given in the following table. For the JT3C-6 engine, the dense smoke emissions at takeoff power were largely caused by the water augmentation in this engine. The water injection is used for additional thrust on takeoff from a standing start to an altitude of approximately 500 feet.

Engine Number and Type	<u>Power Setting</u>			
	Idle	Takeoff	Climb-out	Approach
501-D13 Turboprop	$\leq 1/2$	$\leq 1/2$	$\leq 1/2$	$\leq 1/2$
JT3D-3B Tubofan	0	1 1/2-2	1 1/2-2	1
JT8D-1 Tubofan	3/4	3	3	3
CJ805-3B Turbojet	0	3 1/2	3 1/2	3
JT3C-6 Turbojet with water augmen- tation	-	4	4	3

Suggested Additional Reading

The following references may be obtained from National Technical Information Services, 5285 Port Royal Road, Springfield, VA 22161.

Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions From Mobile Sources, NAPCA Publication No. AP-66, Washington, DC (1970).

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CHAPTER VI.

NON COMBUSTION EMISSIONS AND WATER VAPOR PLUMES

6.1. Discussed below are some of the equipment and the industries that may emit visible plumes. Where available, the size distribution of the particles will be listed. Some of the equipment types are basic to several industries and processes so these types of equipment will be discussed first and then referred to in the industry discussions.

Metallurgical Furnaces

6.2. There are several types of furnaces for melting metals. They are reverberatory, cupola, electric, crucible, and pot. Most of these furnaces discharge high-temperature effluents containing dusts and fumes which are less than 1 micron in size. These effluents must frequently be cooled before they are ducted to a control device. The control device must be capable of high-efficiency collection of submicron particles.

6.3. The reverberatory furnace usually consists of a shallow, generally rectangular refractory hearth for holding the metal to be melted. The furnace is enclosed by vertical walls and covered with a low refractory-lined roof. Combustion of the fuel occurs directly above the metal in the furnace. The heat is radiated from the burner flame, roof, and walls onto the metal. (The radiation "reverberates" within the furnace.)

6.4. The largest reverberatory furnace is the open hearth furnace used in steel manufacture. The charge of metal is introduced through doors in the front wall; finished steel and slag are poured out of a tap hole in the rear wall. Heat is provided by passing a luminous flame with excess air over the charged metal.

6.5. Other reverberatory furnaces are cylindrical and may be fired by a flame which enters the end of the cylinder or is directed tangentially along the side of the cylinder. These furnaces are frequently used in nonferrous (that is, excluding iron and steel) industries for smelting small amounts of aluminum, brass, and alloys of several metals.

6.6. The cupola furnace is normally used in gray iron foundries, where iron is melted and poured into a mold or casting. This furnace is also used to melt copper, brass, bronze, and lead.

6.7. A cupola is a refractory-lined cylinder open at the top and equipped with air inlets (called tuyeres) at the bottom. Alternate layers of metal, coke and limestone are dumped from a charging door in the side of the cupola onto a burning coke bed in the bottom of the furnace. The combustion air for burning the coke is forced upward through the tuyeres and layers of charge by a blower. The heat generated by burning the coke melts the metal, which is drawn off through a tap hole. The charging and melting is a continuous operation. Large amounts of fine particles are carried off in the gases.

6.8. There are four types of electric furnaces: direct arc, indirect arc, resistance, and induction.

6.9. In the direct-arc furnace, graphite and carbon electrodes are placed below the slag cover of the metal. The current passes from one electrode through the slag, through the metal charge, and back through the slag to the other electrode. The heat is generated by radiation from the electric arc between the electrodes and from the resistance to the passage of electricity in the metal.

6.10. In the indirect-arc furnace the metal charge is placed below the electrodes and the arc is formed between the electrodes and above the charge. Indirect-arc furnaces are used mainly in the steel industry.

6.11. The induction furnace consists of a crucible within a water cooled copper coil. An alternating electric current in the coil around the crucible induces eddy currents in the metal charge. The movement of these eddies develops heat within the mass of the charge. This furnace is used for the production of both ferrous and nonferrous metal and alloys.

6.12. In the resistance furnace, the electrodes may be buried within the metal charge or placed above it. The charge itself acts as the electrical resistance and generates the heat. The resistance furnace is used in the smelting of ores to produce ferroalloys at temperatures up to 6000°F.

6.13. A crucible furnace consists of a large, covered metal pot lined with refractory materials such as clay-graphite mixtures or silicon carbide. There is a small hole in the lid for charging the metal and exhausting the products of combustion. The crucible of refractory material rests on a pedestal in the center of the furnace and flames from gas or oil burners are directed tangentially around it. This

furnace is used for melting metals with melting points below 2500°F.

6.14. Pot furnaces may be cylindrical or rectangular and consist of an outer shell lined with refractory material, a combustion chamber, and a pot. The pot is made of iron or steel and in it are placed metals which will melt below 1400°F. The pot rests in the furnace which supports it above the floor of the combustion chamber. When melted, the metals in the pot are removed by tilting the pot or by pumping or dipping.

Driers

6.15. A drier is a device for removing water or other volatile material from a solid substance. Air contaminants emitted include dusts and vapors.

6.16. A rotary drier consists of a rotating cylinder inclined to the horizontal with material fed from the higher end and discharged at the lower end. In the direct rotary drier, heated air or combustion gases flow through the cylinder in direct contact with the material. Air flow may be in either the same or the opposite direction as the flow of material. Dust carryout increases proportionately to the square of the increase in air flow through the drier.

In another type, the indirect rotary drier, heat is applied by combustion gases on the outside of the cylinder or through steam tubes inside the cylinder.

6.17. The direct rotary drier has "flights" attached to the inside of the cylinder. As the cylinder rotates, the flights pick up the material and shower it down through the gas stream. Thus, the direct rotary drier has very high potential for dust emissions. It

cannot be used for drying fine material because loss of product would be excessive. Indirect rotary driers are usually used for drying powdery material since they have less tendency to emit dust.

6.18. The flash drier consists of a furnace or source of hot gases, a device for dispersing the wet material through the gases, a duct through which the gases convey the material, and a collection system for removing the dried material from the gas stream.

6.19. The spray drier consists of a drying chamber, a source of hot gases, a device for atomizing the solution particles to be dried, and a means for separating the dry product from the exhaust gases. Atomization is achieved either by disks which rotate at a high speed, high-pressure nozzles, or by nozzles that use air or by steam to break up the particles. The dried product is generally separated from the exhaust gases and collected in a cyclone separator.

6.20. A tray or compartment drier consists of a chamber containing racks on which are placed trays of wet material to be dried. Heated air circulates over the wet material until the material reaches the desired moisture content.

Terminology in Metallurgical Processing

6.21. The metallurgical industry can be divided into primary and secondary metals industries. The primary metals industries produce the metal from ore. The secondary metals industry includes the production of alloys and the recovery of the metal from scrap and salvage.

6.22. The initial objective of metallurgical operations is to convert the metal ore to a purer form of the metal and then to mix it with other elements to form an alloy. Some of the processes used in these purifying operations are smelting, refining, electrolytic reduction, sweating, and sintering. Sometimes, two of these terms describe the same process.

6.23. The process of heating ores to a high temperature in the presence of a reducing agent such as carbon (coke) and of a fluxing agent (such as limestone) to remove the accompanying clay and sand is termed smelting.

6.24. In the smelting of iron ore the ore is heated in a blast furnace with coke and limestone at a temperature above the melting point of iron and slag (a mixture of the impurities and the limestone flux). The molten iron (the more dense material) and molten slag (the less dense material) are removed separately from the furnace. The limestone flux helps to purge the metal of impurities and renders the slag more liquid.

6.25. Electrolytic Reduction - In this process a molten compound containing the metal is placed in an electrolytic cell known as a pot, which consists of a steel tank lined with refractory insulating bricks. The compound is decomposed by a continuous direct electric current flowing between the cathode and the anode. The purified metal will flow to one of these electrodes and be deposited there.

6.26. Roasting - This process involves heating the material to a temperature not high enough to melt the material but high enough to cause it to oxidize or become pulverized. The process can also be called calcining.

6.27. Sweating Furnace - Sweating can be accomplished in a furnace when the raw material is composed of two metals having different melting temperatures. The sweating furnace temperature is carefully controlled so that the metal with the lower melting point becomes liquid and flows from the furnace. After this metal is removed, the furnace burners are extinguished and the metal with the higher melting point is raked from the hearth.

6.28. Sintering - A mixture of ore-bearing fine particles and fuel such as coal or coke is burned. The object is to partially melt or sinter the material into relatively coarse particles that are more suitable for other metallurgical operations than were the fine particles.

6.29. Quenching - The immersion of hot metals or coke in liquid baths in order to effect rapid cooling is termed quenching. The purpose of quenching ordinary steel is to harden it.

6.30. Materials that will resist change of shape, weight, or physical properties at high temperatures are known as refractories. The materials that are chiefly used for refractories are fire-clay, silica, kaoline, diaspore, alumina, and silicon carbide. Refractories are used most often in the form of bricks.

Iron and Steel Mills

6.31. To make steel, iron is reduced to pig iron in a blast furnace (smelting) and most of its impurities are removed as slag. The pig iron is transformed into steel in open hearth (reverberatory) furnaces, basic oxygen furnaces, or electric furnaces, where carbon, manganese, silicon, and other impurities are oxidized to form gases and slag. The concentrations of the impurities are reduced to the limits specified for steel.

6.32. The blast furnace is the chief means for reducing iron ore to pig iron. The reduction process

is carried out at a high temperature and in the presence of a fluxing substance. Furnances may be 90-100 feet high and of varying diameters. At the top of the furnace is a double bell, which forms an air lock for the admission of materials during continuous operation of the furnace.

When in use, the blast furnace is first charged with alternate layers of coke, ore, and limestone. The coke is ignited at the bottom and is rapidly burned under the influence of a forced draft of air blown from the base upward through the furnace. As the coke is burned away, the material moves downward in the furnace while the stack is kept full by fresh charges admitted through the bells. The iron at the bottom is tapped off at intervals through an "iron notch." The lighter slag may also be tapped off through a "cinder notch."

As the hot gases from the combustion region pass upward from the furnace they heat the fresh charges. They then pass out of the furnace through ducts which carry them to purifying equipment. This gas contains about 25 percent carbon monoxide with the remainder being chiefly inert gases. After the gas is passed through dust collectors and scrubbers, it can be burned in stoves which preheat the air going into the blast furnace.

6.33. "Slips" are the principal operating factor which causes particulate pollution from blast furnaces. A slip results from arching of the charge of coke, limestone, or iron ore across the inside of the furnace. When the arch finally breaks and the burden slips downward, there is a rush of gas to the top of the furnace, which develops abnormally high pressures that cannot be handled by the gas-cleaning equipment.

When this occurs, safety valves open to relieve the pressure and to discharge a dense black or red cloud of dust to the air. Slips reduce efficiency and the steel industry is constantly striving to reduce their incidence. Even under normal conditions most of the particles emitted from blast furnaces are larger than 50 microns.

6.34. The basic oxygen converter is a cylindrical container open at one end for charging and pouring and for oxygen injections. In this steel-making process, oxygen is blown at high velocity through a water-cooled pipe downward onto the surface of the mixture of molten pig iron, scrap iron, and scrap steel. This results in violent agitation and mixing of the oxygen with the iron. Rapid oxidation of the dissolved carbon and silicon follows forming slag and gases.

6.35. Sintering plants convert iron ore fines and blast furnace flue dust into a courser material more suitable for charging to a blast furnace. This is done by applying heat to a mixture of the iron-containing materials and coke on a slow-moving grate through which combustion air is drawn.

6.36. Major sources of dust in sintering plants are the combustion gases drawn through the bed and the exhaust from the grinding, screening, and cooling of the sinter. Most of the particles discharged in the sintering process are large and fall out of the air as dustfall.

6.37. Most of the coke used in blast furnaces is produced in "by-product" coke ovens from bituminous coal. The by-product gases from the coke ovens are processed in a by-product plant, where such items as tar, ammonia, and light oils are removed. The remaining coke-oven

gas is used as fuel in a variety of furnaces throughout the steel plant.

6.38. The coke plant consists of a battery of long, narrow firebrick ovens separated by combustion chambers. Coal is introduced into the red hot ovens through holes in the top of the battery. When the coking is finished (17-18 hours), doors at the ends of the oven are opened and a pusher ram shoves the entire charge of coke into a railway car. The hot coke will burn in the air until the car is conveyed to a quench tower where huge quantities of water are used to extinguish the burning. Dust, steam, and gas emissions occur during charging, discharging, and quenching operations. Since the ovens in a battery are sequentially operated, the pollutants are discharged at a fairly constant rate. Most of the smoke and dust emitted at the coke oven site result from the inadequacies of the charging process, but there is also leakage of smoke and gases because of poorly fitted or sealed oven doors. Visible emission regulations for by-product coke plants vary from State to State. At the present time there are no Federal new source performance standard regulations, but it is anticipated there will be by late 1978 or early 1979. Because of the many points and kinds of potential visible emissions from the coke plants, it is extremely difficult to interpret a Method 9 regulation. Charging of coal and the pushing of coke are the main points of concern, and inspectors should be familiar with the coke plant operations and particularly concerned with good mechanical maintenance by the operators. Charging coal into the oven is estimated to account for 60 to 70 percent of the total emissions problem of coke over batteries. In Allegheny County, Pennsylvania, there are 20% visible emissions allowed for charging and

pushing but no visible emissions allowed for top side leaks. In West Virginia, for coke ovens built after 1972, visible emissions allowed are 30% for 1.5 minutes per charge.

6.39. Air contaminants are emitted from an open hearth furnace throughout the process, which may last 10 hours. Oxygen injection (lancing) into the furnace speeds the process but increases the amount of air pollution emitted. The pollutants emitted are fumes, dust, and gases, with up to 90 percent being the red iron-oxide fumes. Other contaminants may arise from the grease and oil contained in the steel scrap. About 50 percent of the emissions are particles less than 5 microns in diameter.

Open hearth shops often contain several furnaces, each having an exhaust stack. Because of the cost of pollution control and the growing obsolescence of open hearth furnaces, they are being replaced by basic oxygen furnaces and electric furnaces.

6.40. More emissions are created by basic oxygen furnaces (BOF) than by open hearth furnaces; however, all BOF's in the United States are equipped with electrostatic precipitators or venturi scrubbers. The open mouth of the BOF converter is covered by a hood, and the emissions are conducted to the collectors. The particle size of the emissions is small; 85 percent are less than 1 micron in diameter.

6.41. In the steel industry, electric arc furnaces are smaller than other types and are used primarily to produce special alloy steels. Heat is furnished by direct-arc electrodes extending through the roof of the furnace. Dust, fumes, and gases are emitted, but only 40

to 50 percent of the dust is iron oxide, an amount considerably less than that emitted by the other furnaces. Approximately 70 percent by weight of the particles are smaller than 5 microns. Over 95 percent effective collection can be achieved with appropriate hooding and high-efficiency collection equipment.

Gray Iron Foundries

6.42. Gray iron foundries melt and cast iron. The cupola, electric, and reverberatory furnaces are used; however, the cupola is the one most often employed. Plant sizes range from small job cupolas operated several hours a day to large units operated continuously for several days.

Particulate emissions are composed of iron oxide, dust smoke, oil, grease, and metal fumes. Between 20 and 25 percent of the dust and fume particles are less than 5 microns in diameter. The dust in the discharge gases arises from dirt on the metal and from fires in the coke and limestone charge. Smoke and oil vapor come primarily from partial combustion and from distillation of oil on the greasy scrap charged to the furnace.

The exhaust gases which carry the particulates are hot and voluminous, thus requiring a control system designed to handle large flows. The most effective control system incorporates an afterburner to eliminate combustibles and a fabric filter to collect dust and fume. Coolers must be installed to cool the effluent before it reaches the baghouse.

6.43. Other possible sources of particulates at foundries are the core ovens which bake the cores used in the sand molds. The cores contain binders that require baking to develop the strength needed to

resist any erosion and deformation when the molten iron is poured into the mold. Sometimes, when special binders are used in the core, the ovens will emit fine aerosols that can have excessive opacities and cause eye irritation. Normally, an afterburner can control these pollutants.

Nonferrous Metallurgical Industry

6.44. The primary and secondary recovery of copper, lead, zinc, and aluminum are the chief nonferrous metallurgical industries.

6.45. Part of the production of aluminum involves the electrolytic reduction of alumina (an oxide of aluminum) in a pot that also contains cryolite and fluoride salts. The effluent released during the pot reduction process contains hydrogen fluoride, fluoride fumes, and fine particles of alumina and carbon. The emissions from some pot furnaces also contain hydrocarbon tars.

6.46. Secondary aluminum operations involve making lightweight metal alloys for industrial castings. Crucible furnaces, reverberatory furnaces, or sweating furnaces may be used. Fluxes help remove the dissolved gases and oxide particles from the molten bath. Chlorine gas is lanced into the molten bath to reduce the magnesium content. It forms aluminum chloride fumes having a small particle size. If the scrap charged is oily or greasy, smoke is given off. The fluxes used also produce particulate matter.

6.47. The primary smelting of lead and zinc involves converting the sulfide of both ores to oxide through roasting and sintering operations. A mixture of sinter, iron, coke, and limestone flux is charged into blast

furnaces where the burning of the coke reduces the lead oxide to molten lead before being tapped off. The effluent gases from the roasting, sintering, and smelting operation contain considerable lead dust.

6.48. Zinc oxide from the roasting of the ore or from processing the slag from the lead smelter can be converted into metallic zinc by the electrolytic reduction or by distillation in retorts or furnaces. The distillation involves the heating of a mixture of zinc oxide and coke until a zinc vapor is formed and the oxygen in the zinc oxide combines with the carbon in the coke to form carbon monoxide. The zinc vapor passes into a condenser where it is converted into a liquid.

During this refining process, zinc fumes and dust are discharged. In spite of hoods, baghouses, and electrostatic precipitators, the white zinc oxide fume arising from the plant is a distinctive characteristic of a zinc retort plant.

6.49. Scrap and salvage are the raw materials of the secondary metals industry. A substantial quantity of lead is recovered from automobile batteries. Various types of furnaces are used. The discharge of air contaminants from melting furnaces is generally caused by the excessive temperatures and by the melting of metal contaminated with organic material. If fuming fluxes such as ammonium chloride are used in zinc smelting, a fume of ammonium chloride will be observed above the molten metal.

6.50. Over 95 percent of the particulate emission from the secondary smelting of zinc and lead are less than 5 microns in diameter. Much of this is composed of oxides of lead and zinc, but there are also sulfides

and sulfates. Under high temperatures, zinc vapor will form the white zinc oxide fume. Both lead and zinc oxide fumes produce very opaque effluents.

6.51. The recovery of copper from copper sulfide ore involves roasting in multiple hearth furnaces, smelting in reverberatory furnaces, and "converting" by passing thin streams of air through a mixture of iron and copper sulfide. These processes emit CO, sulfur oxides, nitrogen oxides, and a fine particulate plume. The particulates consist of oxides, dust, and sulfuric acid mist.

6.52. The plumes from the primary smelting of copper, lead, and zinc contain concentrations of sulfur oxides that are quite large compared with the other large source-coal and oil-fired power plants.

6.53. Copper is called brass when alloyed with zinc and is termed bronze when alloyed with tin. The remelting of nearly pure copper and bronze produces only small amounts of metal fumes due to high boiling temperatures and low pouring temperatures of copper and tin. However, the secondary smelting of brass can produce zinc oxide fumes consisting of submicron particles.

Petroleum Refineries

6.54. Major sources of particulate matter at refineries are catalyst regenerators, sludge burners, and the air-blowing of asphalt. Minor emissions come from heaters, boilers, and emergency flares.

6.55. Modern refining processes include many operations using solid-type catalysts. These catalysts become contaminated with coke buildup during operation and must be

regenerated by burning off the coke under controlled combustion conditions. The flue gases from the regenerator vessel may contain hot catalyst dust, oil mists, aerosols, carbon monoxide, and other combustion products. If no control devices are used, a visible plume will be emitted. Its degree of opacity will depend upon the atmospheric humidity.

6.56. Two catalytic cracking processes are used: fluid catalytic cracking (FCC) and, less frequently, thermofor catalytic cracking (TCC)- The catalyst regenerator will be different for each catalytic cracking reactor:

- (a) The generator for the FCC units may be located alongside, above, or below the reactor. These regenerators normally have a vertical cylindrical shape with a domed top. External size varies from 20 feet in diameter by 40 feet high to 50 feet in diameter by 85 feet high. Internal cyclones and external electrostatic precipitators and carbon monoxide boilers are used to control the emissions.
- (b) TCC regenerators referred to as kilns, are usually vertical structures with horizontal, rectangular, or square cross sections. Typically, one may be 10 feet square by 45 feet high. Wet centrifugal collectors are used as dust collectors.

6.57. Asphalt is the residue from crude oil distillation after all the other fractions have been boiled off. The residual asphalt can be refined by air blowing the residue at elevated temperatures. Oxygen in the air combines with hydrogen in the oil molecules to form water vapor. Hydrogen is removed until the asphalt

reaches the desired consistency. The blowing is carried out in horizontal or vertical cylindrical-shell stills equipped to blanket the charge with steam. Air blowing of asphalt generates oil and tar mists and malodorous gaseous pollutants.

6.58. At petroleum refineries, the incineration or open burning of the heavy petroleum residues and inorganic materials such as clay, sand, and acids can be a major source of particulate emissions. This sludge is atomized in much the same way as heavy fuel oil. While the organic material can be burned, the inorganic matter is entrained in the exhaust gases and emitted as fine dust.

6.59. To prevent unsafe operating pressures in process units during shutdowns and startups and to handle miscellaneous hydrocarbon leaks or temporary high-pressure conditions, a refinery must provide a means for venting hydrocarbons safely. One method is to incinerate them in an elevated-type flare. Such flares introduce the possibility of smoke composed of carbon particles resulting from incomplete combustion. Smokeless combustion is often promoted at elevated flares by introducing steam through nozzles at the top of the stack. The steam jets provide turbulence and mixing with the ambient air.

Portland Cement and Lime Plants

6.60. Raw materials for the manufacture of portland (gray) cement are ground, mixed, and blended by either a wet or a dry process. In the wet process the crushed raw materials are mixed with water and ground and mixed wet. In the dry process the ingredients are used dry. Raw materials consist of two basic ingredients--lime-bearing material and clayey-material.

After the raw materials are crushed and ground, they are introduced into a rotary kiln and heated. The kiln is a rotating steel cylinder, lined with refractory brick, ranging from 6 feet in diameter by 60 feet in length to 25 feet in diameter by 760 feet in length. Heating continues until the mixture reaches 2200°F, at which temperature a chemical reaction takes place raising the temperature to 2700°-2900°F. Cement clinkers about the size of marbles are produced, which are cooled and ground to a powder. During the grinding, gypsum is added to prevent the cement from hardening too fast when mixed with water.

6.61. The largest amount of particulate emission at cement plants accompanies the exhaust gases leaving the kilns. Over 85 percent of the particles carried out by these gases are smaller than 20 microns in diameter. Dust is also generated from the rotary driers used in preparation of material for the dry process and from the loading of cement into bags, trucks, and railroad cars.

6.62. Fabric filters and electrostatic precipitators preceded by mechanical collectors are generally the controls used.

6.63. Gaseous contaminants from the combustion of fuel in the kilns are usually minor. Most of the sulfur dioxide from the sulfur in the fuel combines with the lime and alkalies such as calcium oxide.

6.64 Lime is produced by calcining various types of limestone in continuous rotary or verticle kilns lined with refractory material. This is accomplished by heating the limestone in the kiln to 2000°F, driving off the carbon dioxide, and leaving calcium oxide, which is called quicklime. Two of its most important single uses are for refractory materials and steel fluxing.

The dust generated by rotary lime kilns ranges from 5 to 15 percent by weight of the lime produced. Vertical kilns emit 1 percent by weight. About 28 percent of the particles are greater than 44 microns in diameter, which is the size range collected in dustfall jars. About one-third are less than 20 microns in diameter.

Kraft Pulp Mills

6.65. The basis of all paper products is cellulose. The main source of cellulose is wood, although rags can also be used. The fibers of cellulose are bound together with lignin in the pulpwood. There are several chemical pulping processes for separating the cellulose from the lignin: sulfite; sulfate or kraft; soda; and alpha. Over three-fourths of the production is done by the kraft and sulfite processes. Both emit characteristic odors; however, the kraft process emits a greater quantity and there are eight times as many kraft as sulfite mills. The malodorous gases include hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and sulfur dioxide.

6.66. In the kraft process, wood chips are mixed with a cooking liquor of sodium sulfide, sodium hydroxide, and water and cooked under steam pressure for about 3 hours in a large, upright vessel called a digester. During the cooking period the pressure is reduced periodically to prevent overburdening of the digester; this is accompanied by steam emissions.

When the cooking is completed, the bottom of the digester is suddenly opened and its contents are forced into a blow tank. The cellulose then proceeds through several processes to the finished product. The spent black liquor containing the lignin is drained from the

blow tank for processing to recover the chemicals for reuse. It is concentrated in multiple steam evaporators, further concentrated in a direct contact evaporator, burned in a recovery furnace, and dissolved in a smelt tank.

The green liquor is pumped into a causticizer, where the sodium carbonate is converted to sodium hydroxide by the addition of calcium hydroxide for reuse in the digester. The calcium carbonate, also produced in the causticizer, is converted into calcium oxide in a lime kiln and then to calcium hydroxide, which then is reused in the causticizer.

6.67. The major source of particulate emissions in kraft pulping is the exhaust from the recovery furnace. Sodium sulfate, which is nonodorous, is the major particulate. Sodium carbonate and carbon particles are also emitted. As the exhaust gases from the recovery furnace pass to the chimney, some of their heat is used to evaporate the black liquor in the direct-contact evaporator. The water vapor produced by the evaporation can produce a sizable white plume when it condenses in the atmosphere.

6.68. Other particulate emissions are lime dust from the lime kiln; mists from the smelt tank, causticizer, digester, and blow tank, and combustion products and unburned bark from the bark-burning boiler.

Sulfuric Acid Manufacturing

6.69. Basically, the production of sulfuric acid involves the generation of sulfur dioxide (SO_2), its oxidation to sulfur trioxide (SO_3), and the hydration of SO_3 to form sulfuric acid.

The sulfur dioxide can be generated by burning sulfur

or sulfur-bearing materials such as hydrogen sulfide from oil refineries. The highly concentrated sulfur oxide emissions from primary smelters are also used as input to the acid-making process although the contaminants such as dust must be removed from the SO_2 gas if high-quality is to be produced.

6.70. The two main processes of producing sulfuric acid are the chamber process and the contact process. Over 90 percent of the sulfuric acid in the United States is produced by the contact process.

6.71. In the chamber process the SO_2 is oxidized to SO_3 by the reduction of nitrogen dioxide (NO_2) to nitrogen oxide (NO), and then it is combined with water vapor. This is accomplished as the hot SO_2 flows through a Glover's tower, several lead chambers, and two Gay Lussac towers. The function of the Gay Lussac towers is to recover the nitrogen oxides (NO and NO_2). The final Gay Lussac tower is the primary source of emissions in the chamber process. These emissions include nitrogen oxides, sulfur dioxide, and sulfuric acid mist. About 50 percent of the total nitrogen oxides is NO_2 , which characterizes the exit gas by a reddish-brown color.

6.72. The contact process uses a catalyst, vanadium pentoxide, to oxidize the SO_2 to SO_3 in a catalytic converter. The SO_3 gas is cooled in an economizer and then passes to an absorbing tower where most of it is absorbed in a circulating stream of 99 percent sulfuric acid. The SO_3 combines with the water in the acid to form more sulfuric acid. Any unabsorbed SO_3 passes through to a stack to the atmosphere. The tail-gas

discharge from the absorbing tower constitutes the only significant air-contaminant discharge from a contact sulfuric acid plant. Most of these tail gases consist of nitrogen, oxygen, and carbon dioxide, and some sulfur dioxide but the SO_3 which is emitted will hydrate and form a sulfuric acid mist upon contact with the atmosphere. Under improper operating conditions, startups or emergency shutdowns, the opacity of this mist can be very dense. Minor mist emissions may come from the converter, towers for drying SO_2 , tank-car vents, or leaks in the process equipment.

6.73. The predominant factor in the visibility of an acid plant's plume is the particle size of the acid mist rather than the weight of the mist discharged. Acid particles larger than 10 microns deposit readily on duct and stack walls and contribute little to the opacity of the plume. Acid mist composed of particles less than 10 microns in diameter is visible in the absorber tail gases. As the particle size decreases, the plume becomes more dense because of the greater light-scattering effect of the smaller particles.

Nitric Acid Plants

6.74. The ammonia oxidation process is the principal method of producing commercial nitric acid. It involves three main steps

- (a) A mixture of ammonia (NH_3) and air is passed through a catalyst at high temperatures. Nitric oxide (NO) and water are formed.
- (b) When the NO stream is cooled, the NO reacts with the oxygen remaining in the mixture to form nitrogen dioxide (NO_2).

(c) The NO_2 is cooled further and is passed to an absorber where it is absorbed in water to produce a 50 to 60 percent nitric acid (HNO_3).

If a higher strength nitric acid is required, the weak acid is processed in an acid concentrator where some of the water is removed by mixing the nitric acid with concentrated sulfuric acid in a dehydrating column. Some gases are produced in this process and they are passed through an absorber tower to recover weak nitric acid.

6.75. The principal source of emissions in a nitric acid plant is the absorber. The tail gases from the absorber contain nitric oxide, nitrogen dioxide, nitrogen, oxygen, and trace amounts of acid mist. Small amounts of NO_2 are also lost from acid concentrators and acid storage tanks. Nitric oxide is a colorless gas; nitrogen dioxide is red-orange-brown in color.

6.76. Abatement of the effluents from absorption towers can be effected by mixing the gases with natural gas and passing them over a catalyst bed. The nitrogen dioxide and nitric oxide are dissociated and converted into nitrogen, carbon dioxide, and water vapor. These gases are then released from a stack.

Paint and Varnish Manufacturing

6.77. Protective coating manufacturing may include the processing of pigments, natural or synthetic resins, drying oils, solvents, driers, and plasticizers. The pigments give the paint color and covering power. The resins--such as rosin--contribute to the drying speed, hardness, and gloss. The pigments are dissolved in drying oils such as linseed oil, which by oxidation and

polymerization (the combination of several simple molecules into a complex molecule) forms a hard film when applied to a surface. Solvents or thinners, such as turpentine, reduce the viscosity of the paint so that it can be spread easily. Upon application, they evaporate from the surface. The driers, such as cobalt soap, are catalysts which accelerate the hardening of the oil film. Plasticizers may be added to keep the hardened film elastic so that it will not crack when subjected to vibration.

6.78. Much of the manufacturing process consists of cooking these ingredients at elevated temperatures to cause decomposition of the products. As long as the cooking is continued, these decomposition products are emitted to the atmosphere. A cook may average 8 to 12 hours. The quantity, composition, and rate of emission depend upon the ingredients in the mix, maximum temperature, rate of heating, stirring, method of introducing additives, and the extent of air or inert gas blowing.

6.79. Emissions include organics, odors, vapors, fumes, gases, and particulate matter ranging from 2 to 20 microns in dimension. Scrubbers have little effect on most of these small particles.

Hot-Mix Asphalt Batching Plants

6.80. All hot-mix asphalt plants incorporate the following processes: conveying proportioned quantities of cold aggregate (stone, gravel, and sand) to a dryer, heating and drying aggregate in a rotary drier, screening and classifying the hot aggregate in bins, weighing out the desired quantities of aggregate sizes, heating the asphalt oil, mixing the hot aggregate and hot asphalt in the proper proportions, and delivering the

hot mixture into trucks which haul it to the paving site. Strictly speaking, this mixture of aggregates and asphalt cement should be called asphalt concrete or bituminous concrete, but it is frequently referred to as just "asphalt".

6.81. Dust originating in the aggregate is the major atmospheric pollutant from asphalt plants, and the principal source of this dust is the rotary drier. The dust is carried out through the upper end of the drier with the exhaust gases. Other important sources of dust are the vibratory screens, unenclosed bucket elevators, weigh hopper, storage piles and bins, and traffic dust from the yard.

6.82. Most driers employ a single dry cyclone as a precleaner, which collects 70 to 90 percent of the exhaust dust. This precleaner catch is discharged back into the bucket elevator where it rejoins the heated aggregate and continues in the process. Of the particulate emissions from the precleaner, 25 percent are between 5 and 10 microns and 35 percent are less than 5 microns in diameter.

6.83. Elevators, hot bins, and screens are enclosed and normally vented to the inlet of the secondary collector. The stream of dust laden gases is combined with that of the primary collector (cyclone or multi-clone) serving the rotary dryer and this enters into the secondary collector. By the use of high energy scrubbers (approximately 30 inch H_2O pressure drop) or fabric filters, high removal efficiencies are possible; however, a visible water vapor plume will be emitted as part of the exhaust from the wet scrubber. Since regulations have become more stringent, fabric

filters are now in general use. Economics often favor the fabric filter over the venturi scrubber when meeting NSPS.

Phosphoric Acid Manufacture

6.84. Two processes are used to manufacture phosphoric acid. High-purity acid for use in the food, detergent, and plastic industries is produced by the thermal process, also called the phosphorus-burning process. The wet process is used to manufacture less pure phosphoric acid for the phosphate fertilizer industry.

6.85. Phosphate rock contains a compound consisting of calcium, phosphorus, oxygen, and fluorine. This compound can be reduced (driving off the oxygen) in an electric furnace so that pure phosphorus is produced. Pure phosphorus ignites immediately when exposed to air; therefore, it is generally submerged under water. For use as a raw material in the thermal-process phosphoric acid manufacture, the phosphorus is usually converted to a liquid, placed under water, and shipped in a tank car.

6.86. Thermal-process phosphoric acid manufacture involves three steps:

- (a) Oxidizing (burning) the liquid phosphorus by mixing it with air in a combustion chamber to produce the compound phosphorus pentoxide (P_2O_5) vapor.
- (b) Passing the vapor into a hydrator where it is mixed with water or weak phosphoric acid to produce a higher strength phosphoric acid mist.
- (c) Removing the mist from the gas stream in an absorber. The strong phosphoric acid is then

stored for shipment or is treated further if it is to be used in the food industry.

6.87. The principal atmospheric emission from the thermal process is the acid mist emitted from the absorber that fails to be collected by the electrostatic precipitator or mesh-entrainment separators. The mist particles are generally less than 5 microns in diameter.

6.88. This mist is extremely hygroscopic so that, unless there is a high collection efficiency, a dense white plume of 100 percent opacity is emitted from the stack. The plume may range from 40 to 50 percent water vapor. Depending on weather conditions and acid mist concentration, the plume usually dissipates in a few hundred feet.

6.89. In the wet process of phosphoric acid manufacture, finely ground phosphate rock is decomposed by sulfuric acid in a reactor (or digester) tank for a period of several hours. During this process weak phosphoric acid and gypsum crystals are created.

6.90. The slurry of these two compounds is sent to a filter system (e.g., a tilting pan vacuum filter), where the gypsum cake is washed out leaving 32 percent acid.

6.91. This acid is then concentrated to 54 percent in an evaporator or concentrator.

6.92. Phosphate rock may contain as much as 4 percent fluorine. Emissions from wet-process phosphoric acid manufacture consist of rock dust, fluoride gases (primarily silicon tetrafluoride), fluoride particulates, and phosphoric acid mist.

6.93. Most of the particulate emissions come from the reactor and some from the filter. These particulates are often removed by wet collectors.

6.94. The reactor, the evaporator, and the filter are all sources of fluoride emissions.

6.95. Most of the phosphate rock mined in the United States is mined in Florida. This is where most of the wet-process phosphoric acid plants are and where much of the phosphate fertilizer manufacture is carried on.

Phosphate Fertilizer Manufacture

6.96. Three different manufacutring processes produce three phosphate fertilizers, each having a different grade of phosphorus pentoxide (P_2O_5) nutrient. These are normal superphosphate (18 percent), a triple superphosphate (45 percent or 54 percent), and diammonium phosphate (64 percent).

6.97. In each of these processes there are emissions of particulates, silicon tetrafluoride and hydrogen fluoride. The particulate dusts are visible; the fluorides can cause damage to livestock through fluorosis.

6.98. Many of the particulate emissions come during the drying of the fertilizer and during the handling of it on conveyor belts or in curing and storing sheds.

6.99. Dust is also produced in plants that granulate the fertilizer or blend it. In graulation, the particle size of the fertilizer is increased to aid in the handling and storage of the fertilizer.

6.100. Normal superphosphate fertilizer is being replaced by high-analysis fertilizers. It is produced

by mixing dry-ground phosphate rock with sulfuric acid. The mixture is poured into a large enclosed container or "den", where it solidifies. The solid is then shaved off by cutters and stored for drying. The major portion of the emissions comes from the storage building.

6.101. Triple superphosphate is produced by a continuous process in which dried and ground phosphate rock is mixed with phosphoric acid. The product can be treated in several ways:

- (a) It can be discharged to a slowmoving belt where it becomes solidified. Then it will be stored in a curing building. After 30-60 days it is dug out from the "pile" in the curing shed and crushed, screened, and shipped.
- (b) It can be fed as a slurry to a "blunger" where it is mixed by rotating blades and granulation is begun. The granulation is completed in heated dryer kilns.
- (c) The cured and screened triple superphosphate produced in (a) can also be passed through a drum granulator in the presence of steam and then dried in a horizontal rotary kiln.

6.102. The usual methods of control in the phosphate fertilizer industry are scrubbers, inertial separators, and fabric filters.

Soap and Synthetic Detergent Manufacture

6.103. The production of soap normally involves the hydrolysis or "splitting" of fats to obtain fatty acids, followed by boiling the fatty acids with sodium or potassium hydroxide in large kettles for several days.

6.104. After cooking, the soap is dried to remove the

moisture and can be finished in several different forms--bars, flakes, chips, or powder. The hot-air process is used to dry the soap for bars, flakes, and chips. Soap powder is finished by spraydrying--the blowing of hot air upward in tall towers while soap drops are falling downward.

6.105. Synthetic detergents are produced by combining a fatty alcohol or linear alkylate with sulfuric acid and then neutralizing it with caustic. The product is a paste mixed with water. The paste is pumped to a large (possibly 100 feet high by 20 feet in diameter) spray tower where it is dried to the desired moisture content.

6.106. The principal sources of particulate matter in the making of soap and synthetic detergents are the spray drying of products and the handling of dry raw materials. Fabric filters are widely used to control dusts from handling.

6.107. The hot exhaust from the tower contains fine particles together with moisture evaporated from the soap or detergent during the spray drying. Often, the exhaust is passed through both a cyclone and a wet scrubber before it is released.

6.108. The exhaust is close to the saturation temperature, particularly if a wet scrubber is used, and it will form a dense white plume that is principally condensed water vapor.

Wet Plumes

6.109. Most air contains some amount of water in the vapor or gaseous phase. Water in this vapor phase is invisible. Only when it is changed to the liquid or

solid phase does the water become visible as clouds, fog, rain, snow, etc.

6.110. Relative humidity is one measure of the amount of water vapor in the air. The warmer the air is, the more water vapor it can hold without the vapor condensing into the liquid state. Thus, the relative humidity of air can be increased in two ways:

- (a) Adding more moisture,
- (b) Cooling the air.

6.111. If either of these methods for increasing relative humidity is carried on long enough, the air becomes saturated. Any more water vapor added or any further cooling results in the excess water vapor changing phase and becoming visible.

6.112. If hot, moist effluent is released to a cooler atmosphere, the moisture will condense to form an opaque white plume; if the relative humidity of the atmosphere is high, this plume will persist for some distance downwind from its emission point.

6.113. The visible water plumes may be objectionable if they

- (a) Contribute to the formation of ground fogs that obscure visibility for automobiles or airplanes;
- (b) Contribute to icing conditions when they come in contact with very cold surfaces;
- (c) Combine with some other gas (such as sulfur trioxide) to form a harmful pollutant (such as sulfuric acid);
- (d) Are aesthetically displeasing to the neighbors.

6.114. A pure water plume disappears without a trace. It evaporates and mixes in all directions in a wispy pattern.

6.115. Plumes containing both water and dust will leave a trail of particulates after the liquid water evaporates. One method of "reading" these plumes to observe infractions of equivalent opacity regulations is to watch them at the point where the water vapor has evaporated.

6.116. Other regulations specify that only plumes containing "uncombined water" may be neglected in enforcing equivalent opacity regulations. This means that if the water plume contains particulates it should be kept under surveillance for violation of visible emissions standards.

6.117. Water plumes can be distinguished from plumes of white particles in several ways:

- (a) The wispieness of the plume as it evaporates;
- (b) The greater frequency of occurrence and a greater length of plume in cold, wet weather than in warm, dry weather;
- (c) The detachment of the visible plume from the top of the stack in hot, dry weather, when it takes the plume longer to cool to its saturation point.

6.118. Water vapor can be emitted from

- (a) Drying operations that remove water by evaporation from foods, chemicals, detergents, paper, pharmaceuticals, ores, etc.
- (b) Combustion in which hydrogen-containing fuels are used. This is especially true of natural gas combustion and the burning of wet fuel.
- (c) Air pollution control devices that use water to remove the gases or particulates from the

gas stream (for example, spray chambers, spray towers, and venturi scrubbers).

- (d) Evaporation of water to remove combustion or chemical reaction heat from a process (for example, forced and natural draft cooling towers, operations for cooling hot gases to protect pollution control equipment, removal of the heat generated in the thermal process of producing phosphoric acid).

6.119. If visible wet plumes must be eliminated, several methods are available:

- (a) Dilution of the plume by mixing it with hot air;
- (b) Superheating the plume prior to emission so that it will disperse before it condenses;
- (c) Condensing the water out of the plume by cooling it prior to emission.

These are all expensive, however.

Suggested Additional Reading

The Chemical Process Industries, R. N. Shreve, Third Edition, McGraw-Hill, New York, (1967).

Control Techniques for Particulate Air Pollutants, NAPCA Publication No. AP-51, Washington, D. C., (1969). National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Compilation of Air Pollution Emission Factors. Second edition AP-42, (April 1973), U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

Note: Above has been supplemented by six supplements from July 1973 to April 1976.

Air Pollution Engineering Manual, edited by J. J. Danielson, Publication No. AP-40, USEPA, 2nd edition, (1973). National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151.

Background information documents for New Source Performance Standards are available for those sources shown in Section XVI of this manual. Where visible emissions are discussed, rationale is given for the selection of the opacity limitation.

Source: Standards Development Branch
(MD-13), Emission Standards
and Engineering Division, US
Environmental Protection Agency,
Research Triangle Park, NC 27711.

Field Surveillance and Enforcement Guide for
Primary Metallurgical Industries, US Environmental
Protection Agency, EPA-450/3-73-002, Research
Triangle Park, NC, (December 1973). National Technical
Information Service, 5285 Port Royal Road, Springfield,
VA 22151.

US Environmental Protection Agency's Div. of
Stationary Source Enforcement, Washington, D.C.
issues inspection manuals and guidelines on various
industrial categories and a limited amount of these
are available at no cost from the EPA Library,
Research Triangle Park, NC, or at a nominal fee from
the National Technical Information Service, 5285 Port
Royal Road, Springfield, VA 22151 Non-combustion
documents are as follows: Emissions from Hot-dip

Galvanizing Processes, EPA No. 905/4-76-002 NTIS No.
251910 Asphalt Concrete, EPA No. 340/1-76-003 NTIS
No. 245848/AS

CHAPTER VII.
CLASSIFICATION AND IDENTIFICATION
OF SOURCES

Classification

7.1. One reason for classifying sources is to aid one in discussing their emissions of pollutants. Measurements have been made of the quantity and types of pollutants emitted for a given amount of fuel or raw material used in a process. Using these "emission factors," the amount of pollutants emitted from power plants, industry, automobiles, etc., can be estimated. The arranging of sources into categories also makes it easier to point out the similarities in plant appearance, process equipment, and collection devices.

7.2. There are several categories into which one can divide or subdivide air pollution sources:

- (a) Mobile and stationary sources;
- (b) Point and area sources;
- (c) Combustion and noncombustion sources;
- (d) Industrial, steam-electric, residential, and commercial-industrial sources;
- (e) Sources burning coal, oil, gas, or wood versus sources not burning fuel such as forest fires, agricultural fires, or solid waste disposal;
- (f) Reciprocal engines and continuous combustion engines.

7.3. Point Sources are ones whose emissions exceed some designated value (for example, 50 tons/year). Sources with smaller emissions can be grouped together in some manner (for example, all the residences in a certain square mile of a city) to constitute an Area Source.

7.4. An example of a classification system that includes all sources is

(a) Fuel Combustion in Stationary Sources

- (1) Industry
- (2) Steam-Electric Power Plants
- (3) Residential
- (4) Commercial-Institutional

(b) Fuel Combustion in Mobile Sources

- (1) Motor Vehicles
- (2) Vessels
- (3) Railroads
- (4) Aircraft

(c) Industrial Process Losses

- (1) Chemical Processing
- (2) Food and Agriculture
- (3) Metallurgical
- (4) Mineral Products
- (5) Petroleum Refining
- (6) Pulp and Paper
- (7) Solvent Evaporation and Gasoline Marketing
- (8) Other

(d) Solid Waste Disposal

- (1) Municipal Incineration
- (2) On-Site Incineration
- (3) Open Burning

(e) Miscellaneous

- (1) Forest Fires
- (2) Structural Building Fires
- (3) Coal Refuse Burning
- (4) Agricultural
- (5) Other

7.5. These categories can be subdivided further, such as into point and area sources; diesel-and gasoline-powered vehicles; jet and piston-powered aircraft; and particular types of industries.

Identification

7.6. Without experience an inspector must use various methods and clues to determine the origin of the visible plumes he sees.

7.7. To learn the nature of the process, he may use books from the library or other sources describing manufacturing. Also descriptive of the processes and the air pollution arising from them are Federal Government publications.

7.8 The inspector can learn about the processes and their emissions by asking questions of his associates and of plant operators, by observing process operations, and by taking photographs of manufacturing operations and noting the similarities between types of operations.

7.9. Clues to the origin of emissions can be obtained from

- (a) The Company's name;
- (b) Directory of Manufacturers - often published by Chamber of Commerce of the city or by the state;

- (c) Air Pollution files of permits for construction or for operation;
- (d) Surroundings of the source such as objects sitting in the yard. These might include the fuel used, the raw materials, the products, the waste material, and the trucks for carrying out the product;
- (e) The shape of the building housing the process;
- (f) Whether the source of emissions is a stack or whether the emissions consist of dust coming out of the building--called fugitive dust;
- (g) Color of the plume;
- (h) Odor;
- (i) Effects on metal structures, paint, vegetation, etc.;
- (j) Any collection devices for particles such as scrubbers, cyclones, electric precipitators, baghouses, ponds, etc.;
- (k) Flares for burning waste gases;
- (l) Any equipment that is visible such as furnaces, towers, rotary driers;
- (m) Any variation of the plume during the day or during the year which might indicate startup operations, batch operations, or changes in operation with weather; is it a continuous process for 24 hours a day or does it cease at the end of the work day?

7.10. Many visible plumes are wholly or partially condensed water vapor plumes. An inspector should be able to identify these since they generally are not considered as violations of visible emission regulations. Some sources of water vapor plumes include:

- (a) Drying operations;
- (b) Combustion operations in which the waste gases are discharged at temperatures near the dew-point;
- (c) Air pollution control equipment that cleans the plume by spraying it with water;
- (d) Operations in which heat is removed by the evaporation of water.

7.11. The inspector should be able to identify the nature of the particulate, whether it is dust, fume, smoke, mist, vapor, or gas.

7.12. If he knows what type of manufacture is going on, then he should be able to identify the possible component manufacturing processes and their equipment.

7.13. The inspector should determine whether the emissions are in the form of a

- (a) A plume;
- (b) A cloud that has become completely divorced from its source;
- (c) A haze that exists over a portion but not all of a community indicating that a local problem is present;
- (d) "Fugitive" emissions, which do not come out of a stack but from windows and other openings in a building.

7.14. If the emissions are in the form of a plume, the inspector should note

- (a) Whether the plume forms at the top of the stack or a few feet above the stack (a detached plume);
- (b) The body of the plume and how far it rises before bending over; its shape after it bends over can be described as coning, fanning, or looping;
- (c) The point at which it dissipates. This may indicate whether the emission is smoke, fume, or contains water vapor. A fume consists of relatively heavy molten liquid droplets that rapidly condense to a solid or a mist at a dissipation point that is closer to the stack outlet than is the case of smoke particles. The water vapor portion of a plume may evaporate leaving particulate matter that persists for a longer distance.

7.15. For smoke emissions, the color is an indication of the type of combustion problem or the type of fuel:

- (a) Black or gray smoke indicates that the material is being burned with inadequate air or inadequate mixing of fuel and air.
- (b) White smoke indicates either that the fire is being cooled by excessive drafts of air or that the materials being burned contain excessive amounts of moisture.
- (c) Brown or yellow smoke indicates the burning of a semi-solid tarry substance such as asphalt or tar paper. Generally, this fuel has not been raised to a temperature that is hot enough

for best combustion and the mixing with air is inadequate.

- (d) Blue smoke often results from the burning of trash which consists of paper or wood products. The plume is composed of small liquid particles and contains only a few particles of carbon or soot.

7.16. The inspector should make an initial identification of a visible plume by placing it in one of the following classes:

- (a) Emissions from stationary combustion sources which are operated to produce energy;
- (b) Emissions from mobile engines (e.g., gasoline, diesel, jet);
- (c) Emissions that are primarily or totally water vapor;
- (d) Emissions of particulate matter from industrial processes;
- (e) Particulate emissions accompanying construction or demolition;
- (f) Emissions of visible gases;
- (g) Emissions from open-burning incinerators, agricultural burning, and structural building fires.

7.17. The air pollution control officer should be familiar with all of the sources of emission, the process equipment, and the control devices located in his area.

- (a) Sources of visible plumes
 - (1) Steam-electric power plants

- (2) Steam-generating facilities for institutions and schools
- (3) Incineration equipment such as tepee burners, single-chamber and multiple-chamber incinerators, etc.
- (4) Furniture, lumber, and wood products industry
- (5) Cement plants
- (6) Carbon black plants
- (7) Soap and detergent manufacture
- (8) Petroleum refineries
- (9) Steel mills
- (10) Asphalt batching plants
- (11) Phosphate fertilizer manufacture
- (12) Phosphoric acid manufacture
- (13) Pulp and paper manufacture
- (14) Lime plants
- (15) Copper, lead, and zinc smelters
- (16) Nitric acid manufacture
- (17) Coke manufacture
- (18) Gray iron foundries
- (19) Vehicles powered by internal combustion engines

(b) Manufacturing process equipment

- (1) Furnaces
- (2) Kettles
- (3) Ovens
- (4) Cupolas
- (5) Kilns
- (6) Dryers
- (7) Roasters
- (8) Towers
- (9) Cookers

- (10) Digesters
- (11) Quenchers
- (12) Columns
- (13) Stills
- (14) Crucibles
- (15) Regenerators
- (16) Flares

(c) Air pollution collection devices

- (1) Cyclones
- (2) Baghouses
- (3) Electrostatic precipitators
- (4) Wet collectors
- (5) Scrubbers
- (6) Dry centrifugal collectors
- (7) Venturi scrubbers
- (8) Afterburners
- (9) Fabric filters.

Suggested Additional Reading

Compilation of Air Pollutant Emission Factors, Second Edition AP-42 (April 1973) and six supplements dated 7/73, 9/73, 7/74, 1/75 and 4/76, US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

Control Techniques for Particulate Air Pollutants, NAPCA Publication No. AP-51 Washington, DC (1969). Available from National Technical Information Service, Springfield, VA 22151.

"Identification of Effluent Plumes", in Field Operations and Enforcement Manual for Air Pollution Control, Vol. 1, USEPA Publication No. APTD-1100, Research Triangle Park, NC 27711 (1972).

CHAPTER VIII.
RINGELMANN CHART AND
EQUIVALENT OPACITY

8.1. Regulations requiring that plume densities or opacities not exceed a specified standard are logical outgrowths of the original laws which prohibited "excessive or repugnant" as a nuisance. It was a nuisance because it was "excessive or repugnant" to our senses - sight, smell, and, possibly, touch. Thus, an acceptable method of determining whether a plume was a nuisance was to set an emission standard based on visual determination of the effluent--how dense or opaque was the plume?

8.2. It has been shown that with proper training an inspector can evaluate the density or opacity of a plume within 7.5 percent opacity, on the average, and within 15 percent opacity for any individual reading, as compared to measurements made by optical instruments. When his training is supplemented by periodic retesting, the inspector can maintain his plume reading proficiency. On this basis the courts have upheld the Ringelmann and Equivalent Opacity regulations when they are enforced by qualified personnel.

8.3 Emission standards can relate to weight loading as well as optical density or opacity. Compliance with the latter type is easier and cheaper to check. It requires only that an inspector make an observation for a specified time period.

8.4. Although the visual standard is limited to estimations of particles of pollution that obscure vision, its application simultaneously tends to reduce the total weight of all sizes of particles emitted. Thus, the visual emissions standard can supplement the weight loading standard and help to reduce the number of source tests the latter standard would require.

8.5. In some cases to comply with the opacity standard, more efficient equipment operation or more efficient combustion is required of a pollution source. In other cases more efficient air pollution control devices may be necessary. A general theoretical relationship between plume opacity and particulate mass concentration for several types of particles (carbon, liquid water, and iron oxide) for a particular source has been developed.

EPA has established opacity limits for new source performance standards of several industrial facilities as well as mass emission limits primarily because it believes that opacity limits provide the only effective and practical method for determining whether emission control equipment, necessary for a source to meet the mass emission limits, is continuously maintained and operated properly. It has not been EPA's position that a single, constant, invariant, and precise correlation between opacity and mass emissions must be identified for each source under all conditions of operation. Such a correlation is unnecessary to the opacity standard, since the EPA Administrator consistently develops opacity standards for each class of source at a level no more restrictive than the corresponding mass emission limitation with due consideration given to all conditions of operation. Any source meeting the mass limit will therefore also be meeting the opacity limit.

8.6. An inspector's knowledge of the size distribution of particle sizes and weights found in the stack tests of various types of stokers, oil burners, manufacturing processes, etc., may serve as a guide to the relation between opacity and mass of effluent. For example, if 75 percent of the weight of a plume is in particles whose sizes are larger than 5 microns in diameter and only 10 percent is in particles whose diameters are less than 1 micron, then the portion which is scattering light (0.4 to 0.7 micron) is small. Under these circumstances, compliance with the visual standard may not ensure the compliance with the loading standard.

8.7. The Ringelmann chart was developed about 1890 by Maximilian Ringelmann, a professor of agricultural engineering in Paris. It was introduced into the United States in 1897 and first incorporated into law in Boston in 1910.

8.8. The chart is a method of judging the shade of gray of a given smoke plume and was originally applied to the emissions from coal-fired boilers.

8.9. Many regulations state that it is illegal to emit smoke of a darker shade than Ringelmann No. 2 for more than 3 minutes in an hour. This 3-minute grace period is allowed for starting up or soot blowing.

8.10. The State of California through its Air Pollution Control Districts in 1947 extended visual emission standards beyond the use of the Ringelmann chart for gray-black plumes. It also prohibited a plume of any color if the plume's opacity was greater than that of a plume with a shade of Ringelmann No. 2.

8.11. While there are actually two regulations which cover all plumes, both black and nonblack, one regulation could be sufficient for regulating the opaqueness of any plume. However, the Ringelmann standard historically was established first and the equivalent opacity standard was referred to the Ringelmann Chart. Actually, the inspector generally judges the amount of light transmitted through both black and nonblack plumes and then relates this transmission to Ringelmann Numbers as a measure of the smoke density of gray-black smoke and equivalent opacity percentages for colored or white plumes. If he compares the gray-black plume with a Ringelmann Chart, he is equating the 60 percent of light transmitted through a No. 2 plume with the 60 percent of light reflected by the No. 2 Ringelmann Chart. The term "equivalent opacity" refers to the extension of the Ringelmann Chart to judge the degree to which a visible plume of any color obscures the view of the observer. The statement of the equivalent opacity regulation generally includes a clause stating "such opacities as to obscure an observer's view to a degree equal to or greater than does smoke of Ringelmann No. 2 shade." In its new source performance standards, the EPA relates all visible emissions with opacity only. A few States and local agencies also have dropped the use of the Ringelmann standard.

8.12. The definitions of the terms "smoke density" and opacity are the source of much controversy and confusion by defense attorneys attempting to invalidate the entire smoke-reading procedure. The definitions of these terms as they apply to visible emissions are

- (a) Smoke Density - One definition of density is "the quantity per unit volume or area." Another is "the mass of substance per

unit volume." In visual emission usage the first definition is the correct one. When applied to the Ringelmann Chart, density refers to the ratio of the area occupied by the black grid lines to the total areas of each card. Since these grid lines are opaque areas, the smoke density is compared with opacity. The definition is not meant to refer to the weight per unit volume of the plume.

- (b) Opacity - Opacity means the degree to which transmitted light is obscured. In air pollution, the expert reader judges the amount of background, sky, or light that he cannot see through the emission.

The Ringelmann Chart

8.13. The Ringelmann system is a method of reproducing shades of gray by means of a rectangular grid of black lines having fixed widths on a white background. When these grids are viewed from a distance, they appear to form a uniform gray area.

8.14. There are five equal steps between white and black. The grid lines are 10 mm apart for each card. The specifications for the square spaces between the grid lines are

- (a) Card 0 - all white (100 percent of the light transmitted)

- (b) Card 1 - black lines 1 mm thick, white spaces 9 mm square (81 square mm) - 80 percent transmission
- (c) Card 2 - black lines 2.3 mm thick, white spaces 7.7 mm square (59 square mm) - 60 percent transmission
- (d) Card 3 - black lines 3.7 mm thick, spaces 6.3 mm square (40 square mm) - 40 percent transmission
- (e) Card 4 - black lines 5.5 mm thick, white spaces 4.5 mm square (20 square mm) - 20 percent transmission
- (f) Card 5 - all black - 0 percent transmission.

The actual chart as provided by the Bureau of Mines contains only cards 1 through 4.

Since the accuracy required of the chart will not be 1 percent or less, the difference between 59 percent and 60 percent can be considered negligible.

8.15. The Ringelmann Chart published by the Bureau of Mines is the chart that is referred to in air pollution law. This chart provides the shades of Cards 1, 2, 3, and 4 in a single sheet. These are known as Ringelmann No. 1, 2, 3, and 4, respectively.

8.16. If the chart is used while observing smoke, it should be mounted 50 feet from the observer at which distance the lines on the chart merge into shades of gray. The observer glances from the smoke, coming from the stack, to the chart and notes the number of the

card that most nearly corresponds with the smoke shade. When the correspondence is not exact, the reading can be made to the nearest 1/4 Ringelmann Number. A clear stack is recorded as No. 0 and 100 percent black smoke is recorded as No. 5.

8.17. With proper experience during a training period, an observer can fix the shades of the Ringelmann Chart in his memory. The inspector may then make his observations in the field without having a chart with him. The Superior Court of Los Angeles has compared this to one's not needing "a color chart in his hands to recognize a red flower, a blue sky, or a black bird."

Smoke Reading Aids

8.18. Although seldom used and difficult to obtain, a number of smoke reading aids can be used to assist in measuring the Ringelmann number of gray or black smoke. None have the versatility of a trained inspector under varying conditions.

8.19. Smoke Tintometer - This instrument used tinted glasses graduated to the Ringelmann scale for comparison with the smoke. It contains two apertures, one for observing the smoke and one for viewing the clear sky through the opening or through one of the tinted glasses.

8.20. Umbrascope - This is a tube using tinted glass segments which cover one-half of the field of view. The smoke is seen through the other half of the field and is compared with the opacity of the glass. One thickness of the gray glass gives 60 percent opacity and is equivalent to Ringelmann No. 3. Additional

thicknesses of glass give even greater opacity. Thus, no opacity less than 60 percent can be measured with this instrument.

8.21. Smokescope - This instrument consists of two barrels for receiving incoming light and one eyecup for viewing. The stack is viewed through one barrel of the instrument. Light from an area adjacent to the stack enters the other barrel and illuminates a circular standard density film. Half of this film is equivalent to No. 2 Ringelmann and the other half is equivalent to No. 3 Ringelmann. The image of these two half disks is projected onto a screen in front of the eyecup and this image surrounds a small aperture where the smoke is seen. The observer then compares the smoke shade with the two Ringelmann shades. The advantage of this instrument over a Ringelmann Chart used in the field is that the illuminations of the smoke and the reference are both influenced by the same factors. One is not transmitted light while the other is reflected. Thus, the smokescope is automatic compensation for varying light conditions.

8.22. Film Strip - This is called a Smoke Inspection Guide and consists of four densities: 20 percent, 40 percent, 60 percent, and 80 percent transmission. The inspector views the source and matches it as closely as possible with one of the densities on the guide.

8.23. Smoke Comparison Charts - Several charts are available and all of them work on the Ringelmann principle. They have shades of gray corresponding to Ringelmann Numbers 1, 2, 3, and 4 printed on a small, pocket-sized card that the inspector can carry with him. When making comparisons with a plume the inspector should hold the card at arm's length.

8.24. Photoelectric Cells - Photoelectric smoke-metering equipment may be permanently built into a stack. This device measures variations in the intensity of a beam of light passing through the effluent in the stack. As part of the granting of a permit, these may be required to be mounted on a stack for continuously monitoring the emissions. In these devices, a constant light source is used to illuminate a standard photoelectric cell that is located on the opposite side of the stack. The light must pass through any smoke rising in the stack before it reaches the cell on the opposite side. The photoelectric cell produces a current of electricity that is directly proportional to the amount of light falling on the cell.

The main problem with most of these devices is in trying to periodically zero the photocell, especially in continuously operating stacks. Emission buildup on the light source and on the photocell also creates a problem.

8.25. All of these smoke-reading aids, except the photoelectric call, can be used only with the black-gray plumes. There are no aids in this nature for assisting the inspector in judging those plumes which fall under the equivalent opacity regulation.

8.26. The Smoke Reading Aids are sometimes cumbersome and are generally not significantly more accurate than sight reading in establishing opacity violations.

8.27. The lidar (or laser radar) instrument has been proposed as a method of measuring smoke-plume opacity. The lidar is composed of a laser transmitter that emits a very brief, high-intensity pulse of coherent light and a receiver that detects the portion of this light

being back-scattered to the instrument from the aerosols in the atmosphere. When plume opacity is measured, the lidar light is shot through the plume and is scattered backward by the aerosols. The receiver measures the amount of reduction in the intensity caused by the two passages of the light through the plume. At present, this instrument is still quite expensive for routine usage.

Training of Inspectors

8.28. Enforcement agencies have found it possible to train observers to recognize Ringelmann numbers and percent opacities without having a comparison chart before them. The inspectors are taught to judge the plume shade or opacity by relating it to percent of light transmission of a training plume. The training plume is generated by special equipment that regulates the opacity of the plume and measures the opacity by a photocell arrangement in the stack of the generator.

8.29. Training with the smoke generator begins by familiarizing the students with known densities of black and white smoke. Upon the sound of a horn the instructor calls out the meter reading. He will go up and down the Ringelmann and Equivalent Opacity scales.

8.30. Next, the students are given a practice run of 25 black and 25 white shades of smoke. At the completion of this run, a student can grade his performance and determine whether he was reading high or low.

8.31. After these familiarization and practice runs, the students are ready for testing for record. Repeated runs of 25 white and 25 black shades of smoke are made with the smoke generator. In between test

runs, short familiarization runs may be made to reinforce the student's accuracy of judgement.

8.32. A student keeps on observing the testing runs until he qualifies as an expert smoke reader. The requirements are that he must read white and black smoke with an average error not to exceed 7.5 percent opacity in each category and with an error not to exceed 15 percent opacity (or 3/4 of a Ringelmann number) on any reading in each category.

8.33. Additional training may be allowed if the student does not meet the standards. However, if the student is unable to pass the visible emissions test, he can be disqualified from serving as an inspector.

8.34. Training runs may be conducted under a variety of conditions of lighting and background color to simulate actual field conditions.

8.35. To evaluate plumes at night it is necessary to have a source of light behind the plume and to evaluate the transmission of this light through the plume. Nighttime readings should be made a part of the training program if the inspector will be required to make field evaluations at night as part of his duties.

8.36. Readings can also be made of smoke from tailpipes or exhausts of moving vehicles. The observer should

- (a) Read the smoke at its point of maximum density;
- (b) Use a stopwatch to record the accumulated violation time;
- (c) Avoid reading directly into the long axis of the plume, if possible. It may be difficult to have a wide angle between his line of sight and the line of exhaust smoke.

- (d) Take a photograph of the offending vehicle and its plume.

Problems of Reading Smoke
in the Field

8.37. There are several criticisms of visible emission control regulations and the ability of inspectors to enforce them objectively. Many of these criticisms can be overcome by the inspector's following proper procedures in his field.

8.38. Criticism: The opacity or smoke density observation made by an inspector will vary according to the position of the sun, the atmospheric lighting, the background of the plume, and the size of the particles in the plume.

Response: The inspector should strive to make his observations with the sun in the 140 degree sector to his back, with the wind blowing at approximately right angles to his line of sight, and with a background that contrasts with the color of the plume. Multiple observations under varying atmospheric conditions can also be made to reduce the effects of the background and atmospheric lighting. An experienced observer can learn to weigh the opacity conditions in relation to various conditions.

On the other hand, wide variations of the sizes of particles in a plume will affect the light-scattering potential of the plume. In most cases it is the variation in mass emission rates that affect the opacity.

8.39. Criticism: Opacity and smoke-density measurements have not been correlated with other measurement methods.

Response: For two types of particles, D. S. Ensor and M. J. Pilat have developed a relationship between plume opacity and a combination of the following properties: plume diameter, particle size distribution, particle mass concentration, average particle density, and particle refractive index. Thus, their equation includes more variables than plume opacity and mass of emissions; however, if certain assumptions are made, predictions of plume transmittance can be related to particulate mass concentration. The observer should have a knowledge of the processes emitting a visible plume so that he can make a judgment of how normal its appearance is. Its appearance may vary with the sequence of startup operations or with the atmospheric relative humidity.

It is reasonable to assume that the elimination of visible emissions will reduce dust and aerosol emissions; however, the reduction may not be in the same ratio. The small particles between 0.1 and 1 micron that cause the light scattering require more expensive control equipment than the large particles (greater than 10 microns), which obscure light by absorbing it.

8.40. Criticism: Gaseous emissions cannot be determined by visible observations.

Response: Very few gases are visible, consequently, visible emission regulations can constitute only a portion of a full set of air pollution regulations.

The opacity of a reddish-brown plume of nitrogen dioxide gas from a nitric acid plant will indicate the amount of that pollutant that is being emitted. A bluish plume for a boiler burning fuel oil will be an indication of the high sulfur content of the oil.

8.41. Criticism: Visible-emission observations are difficult to apply at night.

Response: If the observer positions himself so that there is a source of light behind the plume or places an auxiliary light source behind a plume, then he may make readings at night.

8.42. Criticism: A wet plume may be judged as opaque although its opacity is really due to the water droplets, which are not considered as pollutants.

Response: Since uncombined water is not normally considered as an air pollutant, some allowance must be made for those visible plumes whose opacity is derived from uncombined water droplets. One method is to require that opacity readings of a wet or steam plume be taken at that point of the plume where the steam has evaporated. If the inspector suspects that the source is in violation, it may be necessary to wait for a hot, dry day when the steam rapidly dissipates. He can then make his observation closer to the stack.

8.43. Criticism: Visible-emission regulations can be circumvented by a polluter if he adds more air to his effluent or builds a new stack of smaller diameter for emitting the same quantity of effluent.

Response: The adding of auxiliary air to the effluent in the stack will reduce the concentration of the pollutant and will reduce the opacity of the plume.

The adding of air to the plume to obtain a lower concentration is specifically prohibited in "circumvention" clauses of some regulations. These prohibit the building and operation of equipment that tends to conceal the emission.

By decreasing the radius of the stack, the distance through the plume will decrease and, since the velocity of the emission increases, the concentration of the effluent through the plume will remain the same. The result is that since the light will pass through a thinner plume, less light will be scattered and the observer will read a lower opacity.

A narrower stack may not fall under the circumvention clause. In this case it may be necessary to order a source test to determine if there is a violation of a process weight, emission weight, or concentration ordinance.

It is also possible that the most opaque portion of the plume may occur at some distance above the stack where the emission loses its buoyancy. The best time for observing such a condition would be a day with little or no wind.

8.44 Criticism: Visible emissions from a point source within a building cannot be read within the building.

Response: The observer should be able to read visible emissions within a building the same way he makes readings at night. There may be some legality involved whether or not local regulations allow this. Los Angeles County gets around this by stating in their regulations that emissions within a building is considered emissions to the open atmosphere.

Advantages of Visible Emission Regulations

8.45 Observers can be trained in a relatively short time and it is not necessary that observers have an extensive technical background.

8.46. One man can make many observations in a day.

8.47. No expensive equipment is required.

8.48. Violators can be cited without resorting to time-consuming and costly source testing. A particulate source test takes a minimum of 1 day for a single stack plus the time needed for laboratory analysis and report writing at a minimum cost of \$1,000 per source.

8.49. Questionable emissions can be located and then the actual emissions determined by source tests, if necessary.

8.50. Control can be achieved for those operations not readily suitable to regular source testing methods, such as leakage from equipment and buildings; loading of grain, coal, and ores; or visible automobile or truck exhaust.

Suggested Additional Reading

"Ringelmann Smoke Chart," U.S. Dept. of the Interior Information Circular 8333, (1967). Publications Center, Bureau of Mines, 4800 Forbes Ave., Pittsburg, PA. 15213.

Optical Properties and Visual Effects of Smoke Stack Plumes, W. D. Conner and J. R. Hodgkinson. PHS Publication No. 999-AP-30, DHEW, Research Triangle Park, N.C. 27711 (1972).

"Plume Opacity and Particulate Mass Concentration," M. J. Pilat and D. S. Ensor, Atmospheric Environment, Vol. 4, pp. 163-173 (1970).

"Calculation of Smoke Plume Opacity From Particulate Air Pollutant Properties," D. S. Ensor and M. J. Pilat, Presented at 63rd Air Pollution Control Association Meeting in St. Louis, Missouri, June, 1970.

"The Relationship Between the Visibility and Aerosol Properties of Smoke Stack Plumes," D. S. Ensor and M. J. Pilat, Presented at the Second International Union of Air Pollution Prevention Associations in Washington, D. C. (December, 1970).

EPA Response to Remand Ordered by U. S. Court of Appeals for the District of Columbia in Portland Cement Association v. Ruckelshaus, EPA-450/2/74/023 OAQPS Research Triangle Park, N. C. 27711 (November, 1974).

CHAPTER IX.
QUALIFICATION PROCEDURES AND
EXERCISE IN RECORDING FOR
QUALIFICATION

9.1. The proficiency test requires the inspector to observe 25 shades of black smoke and 25 shades of white smoke.

9.2. To qualify, the inspector must read each shade with no deviations greater than 15 percent opacity or $3/4$ of a Ringelmann number. His average deviation must be no more than 7.5 percent opacity for each category.

9.3. The field portion of this course consists of reading series of 25 black and 25 white shades of smoke produced by the smoke generator.

9.4. There will be some familiarization runs of both black and white smoke during which the opacity or Ringelmann number will be announced while the smoke is being emitted.

9.5. There will then be a practice run of 50 smoke emissions. Twenty-five black shades will be run followed by 25 white shades or vice versa. The student will record his observations to the nearest $1/4$ Ringelmann number or the nearest 5 percent equivalent opacity. At the conclusion of the 50 emissions, the student will compare his readings against the transmissometer readings, record his deviations, and complete his average deviation.

9.6. Following the practice run there will be repeated runs of 50 emissions during which the student will try to refine his smoke-reading ability until he meets the requirements of average deviation not to exceed 7.5

percent opacity for each category, and no reading deviating more than 15 percent opacity (or 3/4 Ringelmann).

9.7. A Smoke School Training Form will be used to record the readings and deviations and to compute the information required for qualification. It also has spaces for information regarding the observer, the time of day, the weather, and the observer's position in relation to the wind direction, the sun, and the background for the smoke.

9.8. This form must be filled in completely when it is submitted to the examiner by the student who has qualified on a series of emissions.

Instructions to the Student During the Reading of Smoke

9.9. The aim of the training and testing of smoke readers in this course is to produce an inspector whose judgment of plume density will be accurate and unaffected by variable field conditions. His expert observations serve in place of the measurements of a mechanical device, and his accuracy must stand up if the case is brought to court.

9.10. To aid the accuracy of inspectors and to promote uniformity among inspectors' readings, several rules of smoke reading should be followed while the smoke reader is making his observations:

- (a) The sun should be within a 140° sector behind the observer during daylight hours. This avoids the problems arising from the forward scattering of light by the particles in the plume.

- (b) A light source should be behind the plume at night.
- (c) Readings should be made at approximately right angles to the wind direction, and from any distance necessary to obtain a clear view of the stack and background. This might be from 100 feet to 1/4 mile in the case of stacks in the field but not closer than 50 feet in the case of observing the plumes from the smoke generator.
- (d) For plumes not containing water vapor, the inspector should estimate the plume density at a point only a foot or two above the stack at which height the plume is no wider than the diameter of the stack. The inspector should make his observations of water vapor plumes in accordance with local ordinances.
- (e) The inspector should try to read the plume against a contrasting background such as blue sky for black plumes and tree leaves for white plumes.
- (f) The inspector should not stare at the plume, but should look at it only at the prescribed 15 second interval. Staring at the plume will cause fatigue and produce erroneous readings.

9.11. During the inspector's training and testing with the smoke generator, a horn will be sounded when he should look at the plume and make his observation. In between the soundings of the horn he should not stare at the plume. The time interval between the sounding of the horn and the glancing at the stack top by the observer is approximately the time it takes the generator smoke to travel from the generator's transmissometer to the top of the stack.

9.12. If the local agency permits it, the inspector may use small, hand-held Ringelmann Charts or other aids as guides in judging the black and gray shades.

9.13. The inspector should not wear dark glasses while taking the test unless he plans to wear these glasses while making smoke readings in his normal enforcement and inspection duties.

Filling Out the Training Form

9.14. Name and Affiliation of the observer are self-explanatory, as is the Date of the test.

9.15. The Time should be the approximate time when the switch between black and white smoke was made.

9.16. Location refers to the address and city where the test was given.

9.17. The Wind Speed should be estimated by the observer within a 3 to 5 mile-per-hour range. If an anemometer (wind speed instrument) is not available, he may estimate the wind speed by using the Beaufort wind scale.

9.18. To determine the Wind Direction the observer must first know his orientation with respect to north. This can be learned from a map. The direction from which the wind is blowing can then be estimated to 16 points of the compass (N, NNE, etc.) by watching a flag or seeing which way a handful of grass blows when thrown into the air.

9.19. Sky Condition should be filled in as:

- (a) Clear - less than 0.1 of the sky covered by clouds;
- (b) Scattered - 0.1 to 0.5 of the sky covered;
- (c) Broken - 0.5 to 0.9 of the sky covered;
- (d) Overcast - more than 0.9 of the sky covered.

9.20. Observer's Position should show his position in relation to the sun, the smoke generator, and the plume.

9.21. Run No. - Each run during the training session will consist of 25 black (B) and 25 white (W) shades of smoke. The runs will be numbered successively beginning with 1-B and 1-W.

9.22. The student will enter his observations in the Observer's Reading columns. The black smoke readings should be entered as fractions of Ringelmann Numbers, with 0 being the lowest and 5 being the largest. The minimum increment is $1/4$. If appropriate in relation to the laws or regulations of the jurisdiction in which the students work, the observations of black smoke may be recorded in opacity, to the nearest 5 percent. The

white smoke readings should be entered in percent opacity. The lowest possible reading is 0 and the highest is 100. The observations are made to the nearest 5 percent.

9.23. At the end of the run the instructor will read off the transmissometer readings and the student should enter these values in the Transmissometer Reading columns.

9.24. The student will then fill out the Deviation columns. If the observer's reading is less than the transmissometer readings, the difference is entered in the - Deviation column.

9.25. In computing the deviations for the black smoke readings, it will be more convenient to convert the fractional Ringelmann number differences into percents, similar to the white smoke. A deviation of $1/4$ Ringelmann is equivalent to 5 percent, $1/2$ to 10 percent, $3/4$ to 15 percent, 1 to 20 percent, and so on. As can be seen, these conversions to percentages are done by multiplying the Ringelmann deviations by 20.

9.26. The entries in the + Deviation and - Deviation columns are added and their Sum is entered at the bottom of the column. The Number of deviations in each column is also entered at the bottom of the column. These entries can be used by the student to guide him as to whether he is tending to read high or low. If he divides the sum of his deviations by the number of deviations, he can estimate how high or low he is reading.

9.27. In the QUALIFICATION portion of the form, the two sets of boxes refer to the black and white portions of the run.

9.28. In the first set of boxes enter the run number.

9.29. In the second set of boxes, enter the number of readings on which the observer agreed exactly with the transmissometer reading.

9.30. In the third set of boxes, enter the number of readings on which the observer disagreed with the transmissometer by more than $3/4$ of a Ringelmann Number (black) or by more than 15 percent equivalent opacity (white).

9.31. Calculate the average deviation on the black and then the white portion of the run by adding the sum of the + Deviations to the sum of the - Deviations and dividing this by the number of readings (25).

9.32. The Examiner will verify the Training Forms of those students who will qualify.

9.33. To qualify, the student must have no readings of black or white smoke that deviate by more than $3/4$ of a Ringelmann Number or more than 15 percent equivalent opacity, and his average deviation for white and for black smoke must both be less than 7.5 percent.

Suggested Additional Reading

Guidelines for Evaluation of Visible Emissions, R.

Missen and A. Stein. EPA Contract #68-02-1390,
Publication No. 340/1-75-007, U. S. Environmental
Protection Agency, Washington, D. C. (April, 1975).

"Smoke Reading School," in Field Operations and Enforcement Manual for Air Pollution Control, Volume 1, pgs.

4.28 - 4.32. EPA Publication No. APTD-1100, U. S.
Environmental Protection Agency, Research Triangle
Park, N. C. 27711.

ENVIRONMENTAL PROTECTION AGENCY VISIBLE EMISSION TRAINING FORM

1. Name of Observer _____
2. Affiliation _____
3. Date _____ Time _____
4. Wind Speed _____ Direction _____ Sky Condition _____
5. Observers Position _____
6. Corrected By _____

Record Black and/or White Smoke in Percent Opacity (for example: 5 percent smallest division)

RUN NO.					RUN NO.				
Reading No.	Observer Reading	Transmissometer Reading	+ Deviation	- Deviation	Reading No.	Observer Reading	Transmissometer Reading	+ Deviation	- Deviation
1					13				
2					14				
3					15				
4					16				
5					17				
6					18				
7					19				
8					20				
9					21				
10					22				
11					23				
12					24				
					25				

7. Run Number
8. Number Correct
9. Number of Plus Deviations
10. Number of Minus Deviations
11. Average Plus Deviations = $\frac{\text{Sum of Plus Deviations}}{\text{No. of Plus Deviations}}$
12. Average Minus Deviations = $\frac{\text{Sum of Minus Deviations}}{\text{No. of Minus Deviations}}$
13. Average Deviation = $\frac{(\text{Sum of Plus Deviations}) + (\text{Sum of Minus Deviations})}{\text{Total No. of Readings}}$
14. Number of Readings 20% Deviation and Over (or 1 Ringelmann and more)

7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		

CHAPTER X
BASIC METEOROLOGY

10.1. Primary Meteorological Factors Affecting Concentration of Air Pollutants-There are two meteorological factors of primary concern in the life cycle of an air pollutant. These are wind and stability. As Figure 10-1 indicates, we can think of wind primarily as the horizontal motions and fluctuations of the air, while stability can be thought of as an index of vertical turbulence. Since the diffusion of pollutants in the atmosphere is basically dictated by the amount of motion or turbulence in the atmosphere around the source, we can begin to see very quickly why wind and stability are of basic concern to the air pollution meteorologist.

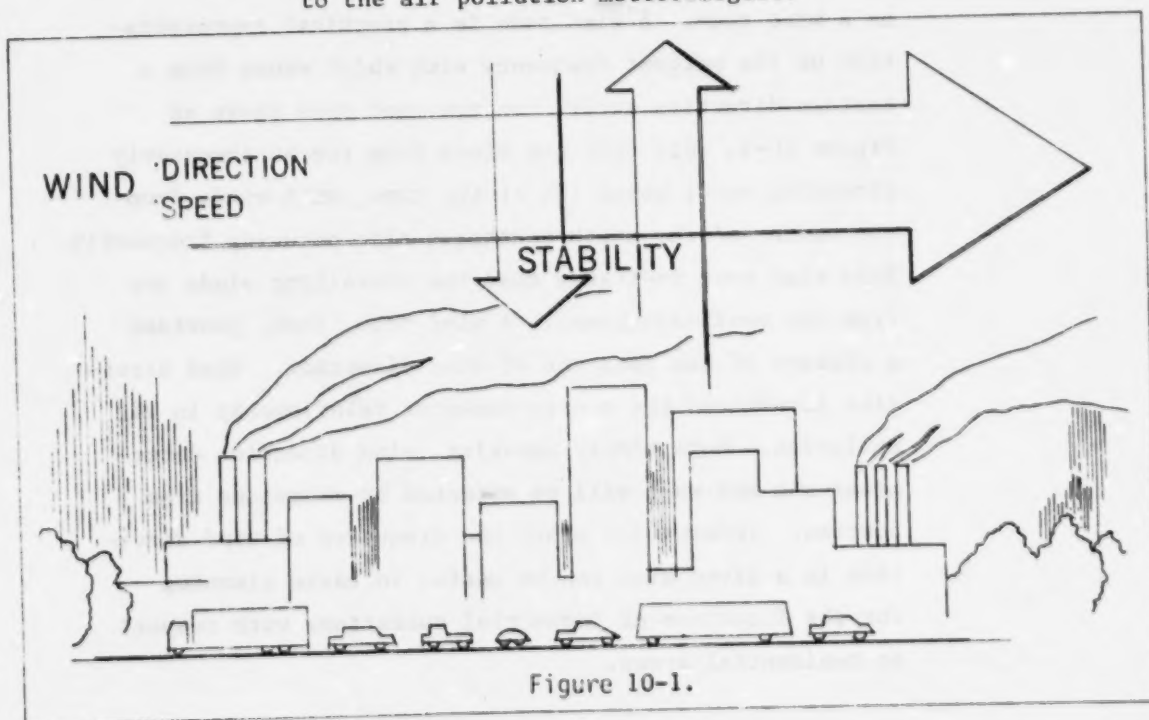
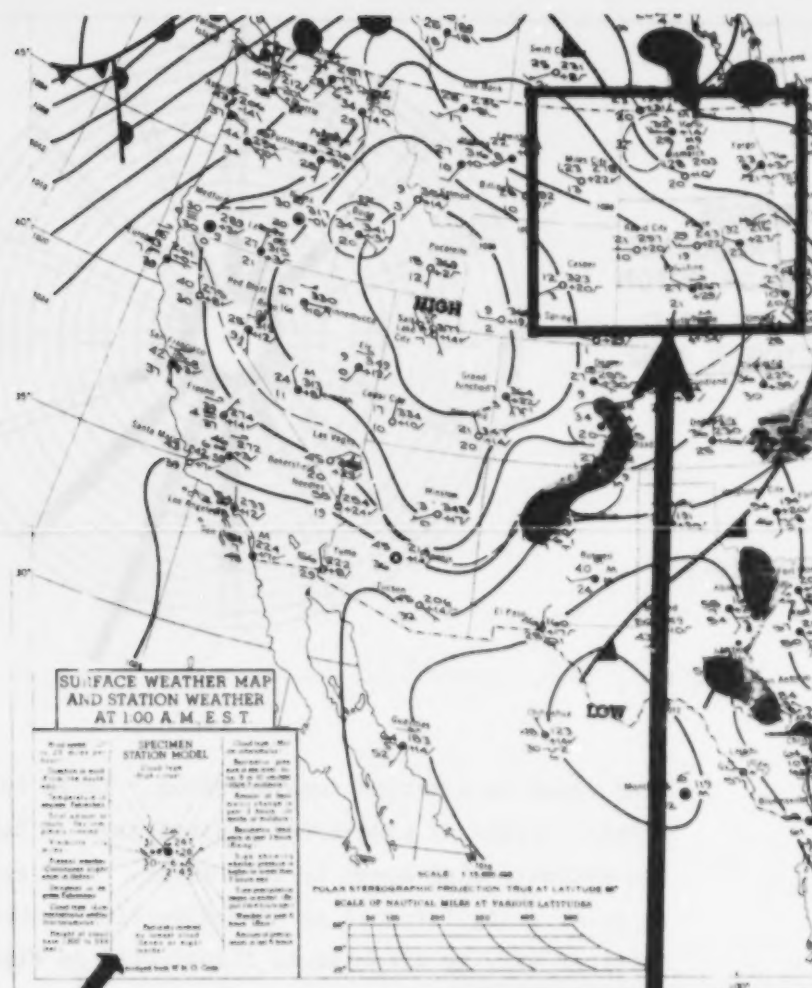


Figure 10-1.

Wind

10.2. Meteorologists usually consider two obvious factors in relation to wind. They are wind direction and speed. When considering the winds at a particular point or over an area, we need to remember that the wind direction is the direction from which the wind blows. Figure 10-2 is a segment of a weather map representing the weather conditions reported at several stations. Note the little flag or arrow that extends from the station circle at Miles City, Montana. This points or flies from the northwest and tells us that the wind is a northwest wind...a wind that blows from the northwest. If you consider this as a "wind arrow" with the speed indicated by the number and length of the barbs, or "feathers," then the arrow flies with the wind, toward the station circle.

In studying the wind patterns-or wind climatology-for a certain location, meteorologists construct what is known as a wind rose. A wind rose is a graphical representation of the percent frequency with which winds from a certain direction occur. On the wind rose shown as Figure 10-3, note that the winds from the northwesterly direction occur about 15% of the time, with winds from the south and the south-southeast also occurring frequently. This wind rose indicates that the prevailing winds are from the south-southeast. A wind rose, then, provides a picture of the patterns of wind direction. Wind direction determines the source-receptor relationship in air pollution. More simply speaking, wind direction determines who and what will be affected by emissions from sources. Information about the frequency of wind direction in a given area can be useful in basic planning for the locations of industrial operations with respect to residential areas.



SURFACE WEATHER MAP
AND STATION WEATHER
AT 1:00 A.M. EST

Wind speed - 20 to 25 miles per hour Direction of wind from the north-west Temperature in degrees Fahrenheit Total amount of clouds - sky with partly cloudy Visibility in miles Pressure - 30.2 Cloud type - Low Height of cloud base - 200 to 300 feet	SPECIMEN STATION MODEL Cloud type High - cumulus Amount of cloud cover in tenths of 100 Barometric pressure in tenths of 100 Sign shows whether pressure is higher or lower than 3 hours ago Time precipitation began or ended (in tenths of 100) Amount of precipitation in tenths of 100
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SURFACE WEATHER MAP
AND STATION WEATHER
AT 1:00 A.M. EST

Wind speed - 20 to 25 miles per hour Direction of wind from the north-west Temperature in degrees Fahrenheit Total amount of clouds - sky with partly cloudy Visibility in miles Pressure - 30.2 Cloud type - Low Height of cloud base - 200 to 300 feet	SPECIMEN STATION MODEL Cloud type High - cumulus Amount of cloud cover in tenths of 100 Barometric pressure in tenths of 100 Sign shows whether pressure is higher or lower than 3 hours ago Time precipitation began or ended (in tenths of 100) Amount of precipitation in tenths of 100
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NOTE

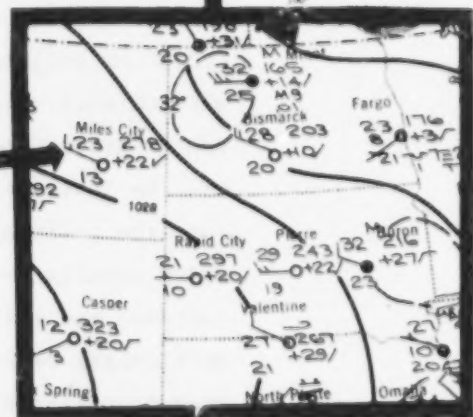


Figure 10-2.

WIND ROSE
- PERCENT FREQUENCY
SEATTLE, WASHINGTON
BOEING FIELD
OCTOBER, 1962

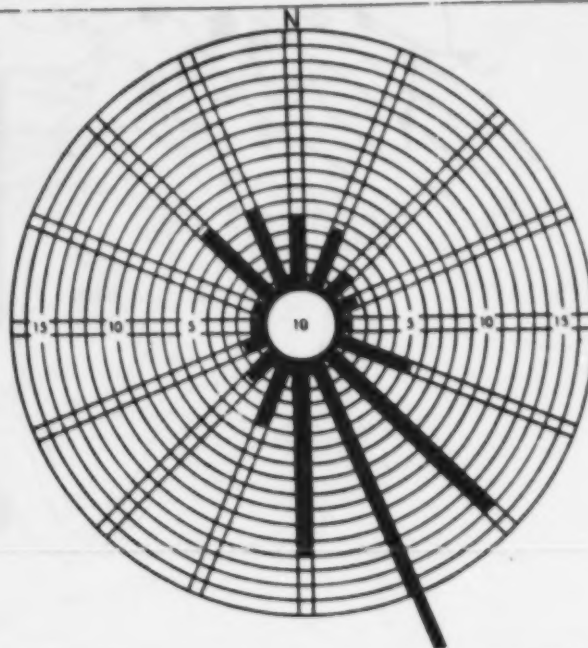


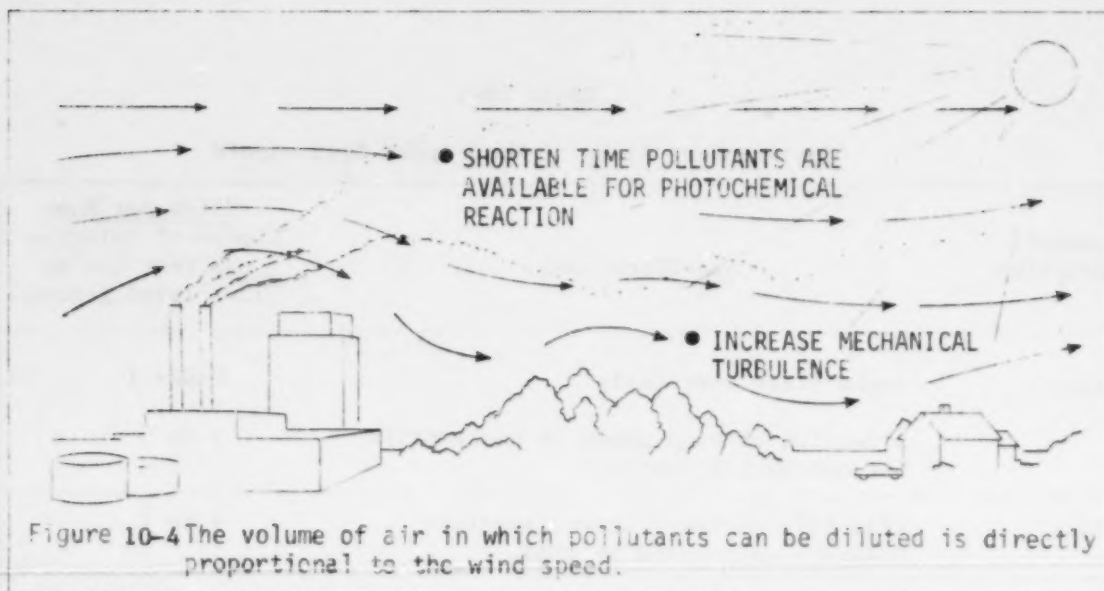
Figure 10-3

Wind speed is a second consideration. Table 10-1 is the Beaufort Scale of wind-speed equivalents. A lay person can estimate wind speed by this table. Wind speed has as great a significance as wind direction in how a receptor will be affected as illustrated in Figure 10-4. Low wind speeds or calm conditions will extend the "life cycle" of pollutants by allowing various chemical and photochemical reactions to occur that produce secondary pollutants. Ground level concentrations of pollutants will be lower when high winds bring in fresh air to dilute the pollutants further. Mechanical turbulence, which results from winds moving over rough terrain, can increase and will hasten the gravitational settling of particulate pollutants, as well as speeding the dispersion of pollutants in the atmosphere. High wind speeds are generally favorable for the dispersion and transport of air pollutants.

Table 10-1

The Beaufort Scale of Wind-Speed Equivalents

General Description	Specifications	Miles per Hour Limits of Velocity 33 feet (10 m) above level ground
Calm	Smoke rises vertically.	Under 1
	Direction of wind shown by smoke drift but not by wind vanes.	1 to 3
Light	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4 to 7
Gentle	Leaves and small twigs in constant motion; wind extends light flag.	8 to 12
Moderate	Raises dust and loose paper; small branches are moved.	13 to 18
Fresh	Small trees in leaf begin to sway; crested wavelets form on inland waters.	19 to 24
	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	25 to 31
Strong	Whole trees in motion; inconvenience felt in walking against the wind.	32 to 38
	Breaks twigs off trees; generally impedes progress.	39 to 46
Gale	Slight structural damage occurs (chimney pots and slate removed).	47 to 54
	Trees uprooted; considerable structural damage occurs.	55 to 63
Whole gale	Rarely experienced; accompanied by widespread damage.	64 to 75
Hurricane		Above 75



The wind around a particular point at a given time is influenced by a number of forces. Three factors are important in the flow of air: the pressure gradient force, the Coriolis effect, and the effects of surface features and topography.

Pressure Gradient Force

10.3. Wind, or air flow, results basically from the presence of high and low pressure systems. Pressure, in meteorological terms, is simply the weight of the atmosphere. Cool air weighs more than warm air. A high pressure system then, is a mass of cool, relatively heavy air, while a low pressure system consists of warm, relatively light air. The rate and direction of the pressure difference between areas of high and low pressure is known as the pressure gradient. The pressure difference exerts a force on an air parcel, causing it to move from the area of high pressure to the area of low pressure. This force is called the pressure gradient force. Thus, winds will tend to blow from a high pressure area to a low pressure area.

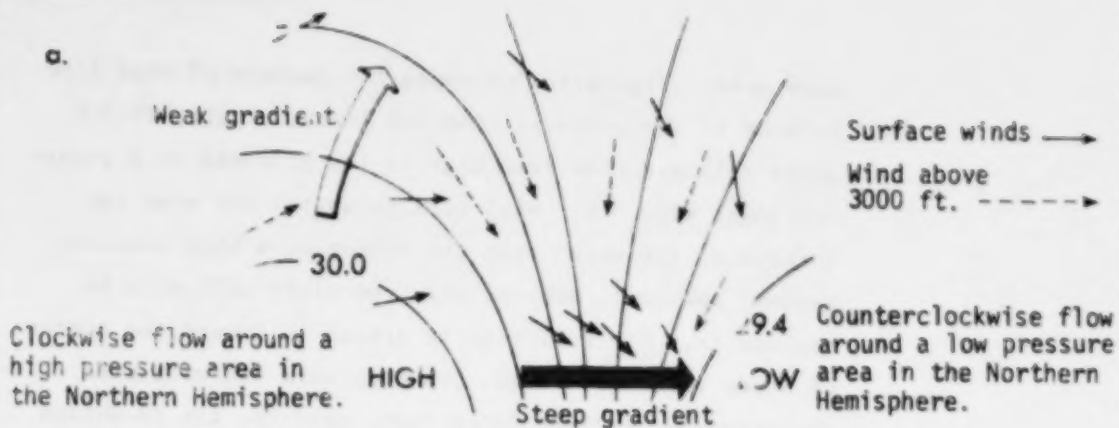
sure area. Figure 10-5-a shows the pattern of wind flow related to the pressure gradient force. Figure 10-5-b shows this air flow from high to low pressure in a cross-sectional view. Air will tend to spiral out near the surface of the earth from the center of a high pressure system, and cool, heavier air from aloft will sink to replace it. Air will tend to spiral in toward the center of a low pressure system, and this warm air will rise. The pressure gradient force then, sets the air in motion from an area of high pressure to an area of low pressure.

Coriolis Effect

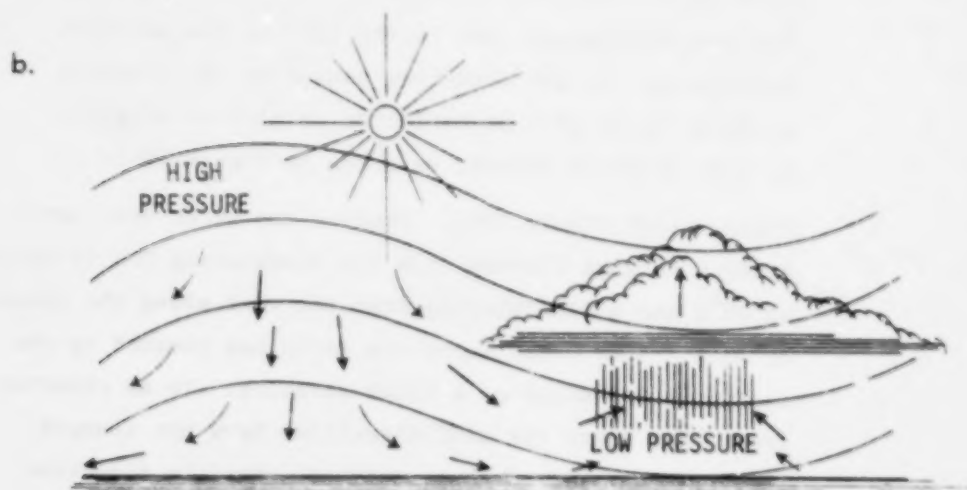
10.4. The basic flow of air is deflected by the Coriolis force. In reality, this is not a force at all, but an effect resulting from the rotation of the earth, and the movement of air relative to the earth's surface.

From a fixed point on the earth, it appears to us that there is a force that deflects winds to the right in the northern hemisphere, and to the left in the southern hemisphere. So any wind flow caused by the pressure gradient force will be deflected or altered slightly by this Coriolis effect, as shown in Figure 10-6.

Please study Figure 10-7. Imagine two winds over North America, a wind blowing from the south along the meridian at 90°W and a wind blowing from the west along the parallel at 40°N . Four hours later the earth has rotated to the east 60° , one-sixth of a total rotation. To an observer from outer space the wind directions have not changed. They have maintained their original absolute direction with respect to a point in space, while the earth underneath has turned. To an observer on the earth, however, it appears that these winds have been deflected to the right. And indeed, since the meridians and parallels have rotated and changed absolute direction, the original

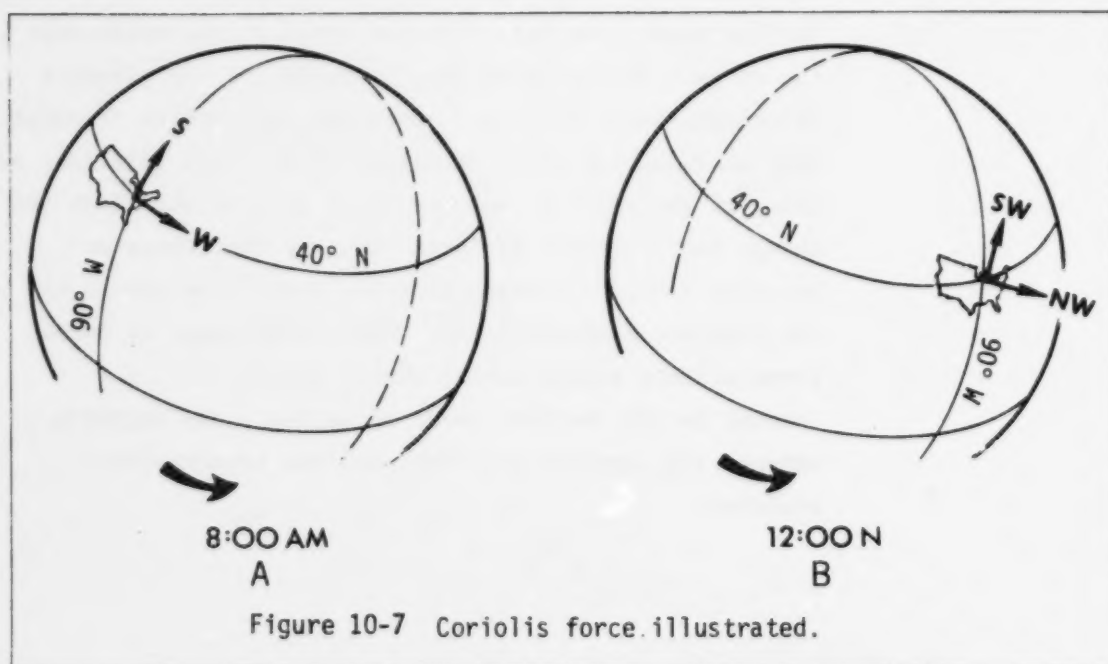
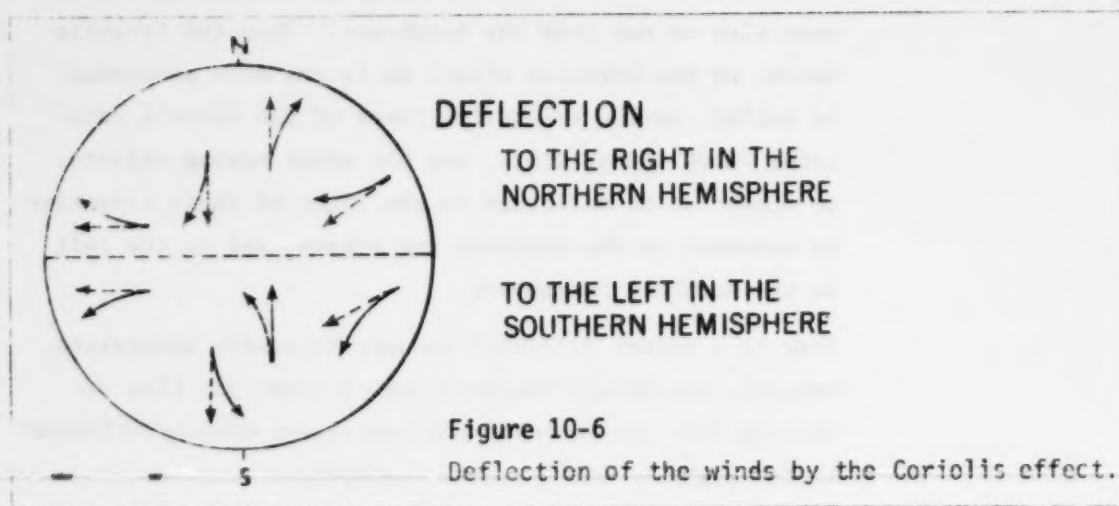


Pressure gradient is the rate and direction of pressure change. In the drawing above (and on weather maps) the solid lines are isobars, lines of equal pressure. Where the isobars are close together, the pressure change is rapid, and the pressure gradient is "steep" or high in magnitude. Here the pressure gradient will exert a greater accelerating force, and there will be greater wind speed. Weak winds can be associated with widely spaced isobars, where there is a weak gradient. The direction of the wind flow is from high to low pressure. But the rotation of the earth will cause this wind flow to be indirect.



Flow of air from a high pressure area to a low pressure area caused by the pressure gradient force.

Figure 10-5



south wind now appears to be from the southeast, and the west wind is now from the northwest. Thus the Coriolis force, or the Coriolis effect as it can more accurately be called, is the deflecting force of the earth's rotation, which causes winds, and all other moving objects, to appear to be deflected to the right of their direction of movement in the northern hemisphere, and to the left in the southern hemisphere.

This is a rather difficult concept to really understand. However, you should remember that a given air flow resulting from the pressure gradient force will be deflected to the right in the northern hemisphere.

Topographical Features

10.5. To this point, two basic influences acting on the winds have been presented: the Coriolis effect (a global or macroscale phenomenon), and the pressure gradient force (a synoptic or continental scale phenomenon). On a still smaller scale, the direction and force of the winds near the surface of the earth are influenced by the presence of topographical features, buildings, and bodies of water. Some of these are shown in Figure 10-8. This friction, or drag, of the surface features tends to slow the winds and change the direction of their flow, so that there are frequent local variations from the basic flow set up by the pressure gradient force. There are, then, at least three effects acting on the winds, ranging from the largest to the smallest scale of motion - the Coriolis effect, the pressure gradient, and the topographical features.

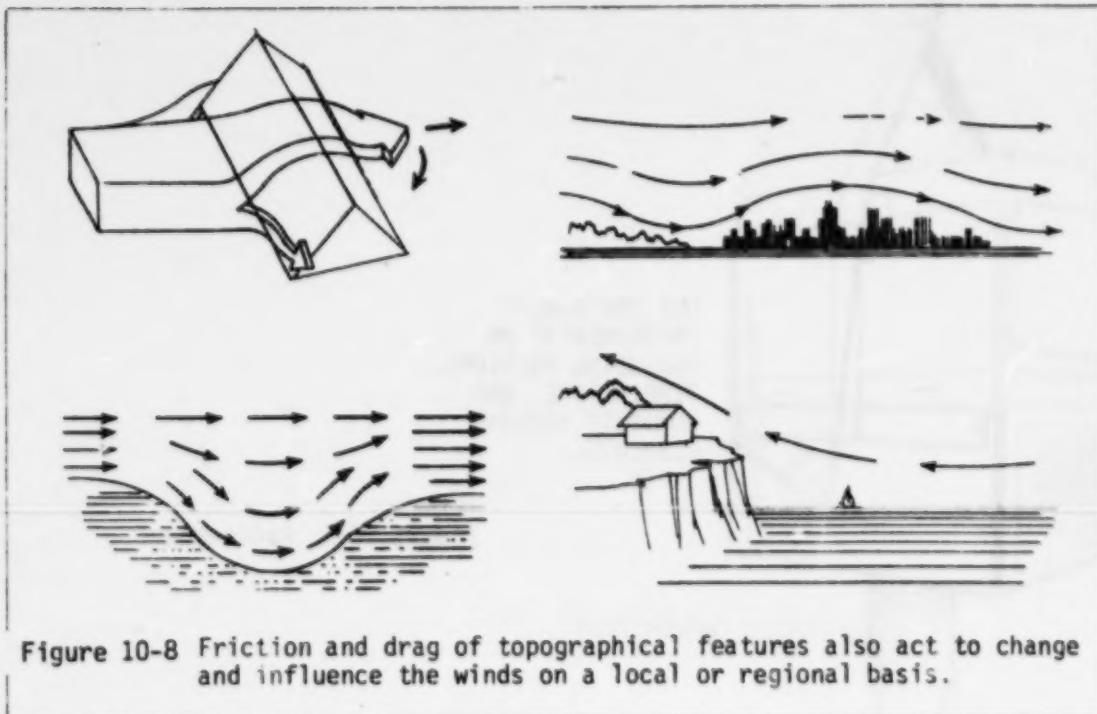
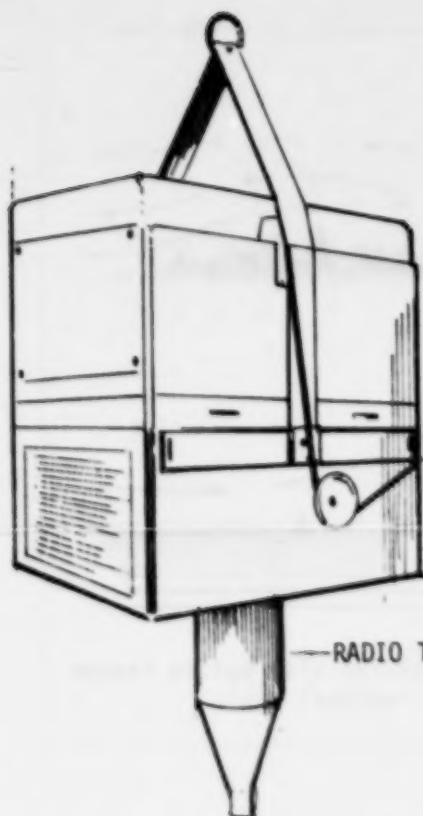


Figure 10-8 Friction and drag of topographical features also act to change and influence the winds on a local or regional basis.

Stability

10.6. The second meteorological parameter of basic concern to the air pollution expert is stability. Stability is defined as the tendency of the atmosphere to enhance or suppress vertical motions. The amount of vertical motions. The amount of vertical motion in the atmosphere over a polluted area will, in part, determine how quickly and effectively these pollutants are dispersed through the atmosphere. An index of vertical motion can be determined by investigating how the temperature changes as we ascend in the atmosphere. This is usually done at weather stations by releasing a radiosonde (Figure 10-9). This box carries sensors and a radio transmitter. As the radiosonde ascends through the atmosphere it sends back information about temperature, pressure, and humidity at various altitudes.

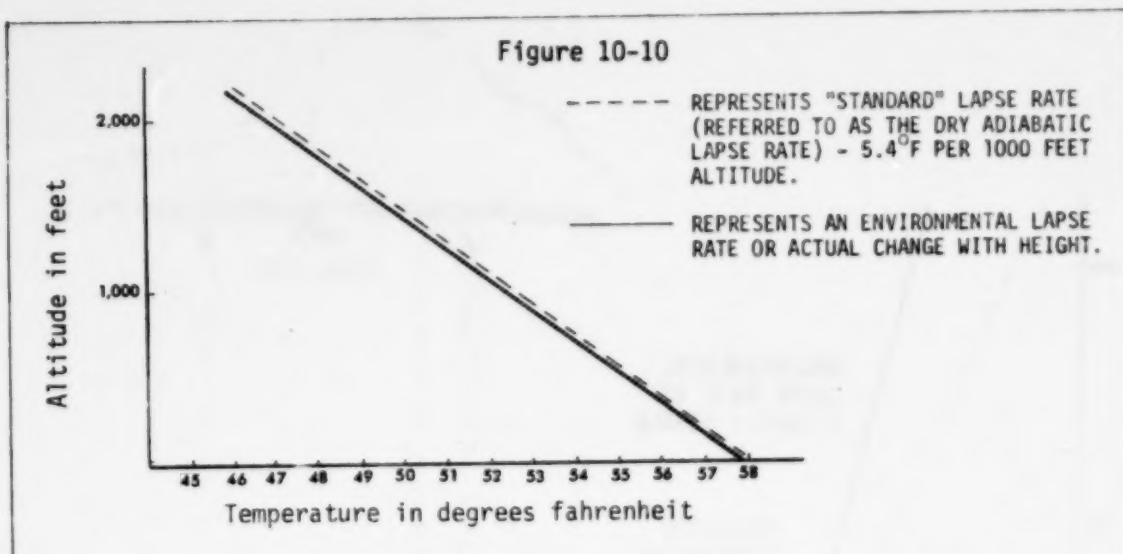


BOX CONTAINING
INSTRUMENTATION
INCLUDING PRESSURE,
TEMPERATURE, AND
HUMIDITY SENSING
ELEMENTS.

Figure 10-9 Radiosonde

RADIO TRANSMITTER

What sort of picture emerges from these readings? Normally, the air near the earth's surface is slightly warmer than that aloft. The warmer, lighter air will rise, and the cooler, heavier air will sink and replace it. This causes an overturning or mixing in the air, which provides a large volume of air in which to mix pollutants. Meteorologists call this rate of temperature change the lapse rate. In order to represent the lapse rate graphically, the meteorologist plots a temperature profile (Figure 10-10). In such a profile the temperature is plotted against altitude and the slope indicated as a solid line called the environmental lapse rate. The dotted line is the "standard" lapse rate. The "standard" lapse rate represents a



drop of 5.4° Fahrenheit for each 1000 feet increase in altitude. When the measured or environmental rate is the same as this standard decrease in altitude temperature, the parcels of air at any height in that environment are in equilibrium, and will not tend to rise or subside unless some outside force is applied. If you think of typical weather patterns, you can easily begin to imagine conditions under which there will be unstable conditions because of a large difference between ground level temperature and temperature aloft. In mid-afternoon on a clear day, the air near the surface will be very warm because the earth is giving off the heat it has absorbed from the sun. Thus, there will be overturning, often called thermal turbulence. A slightly different condition often occurs when there is a cloud cover or windy conditions, and the ground does not receive as much heat, as shown in Figure 10-11. Here, the air near the ground stays nearly the same temperature as the air aloft during the day and does not cool off as much at night. This is called a weak lapse rate. There is still moderate mixing and dispersion of pollutants, enhanced by the likelihood of high winds.

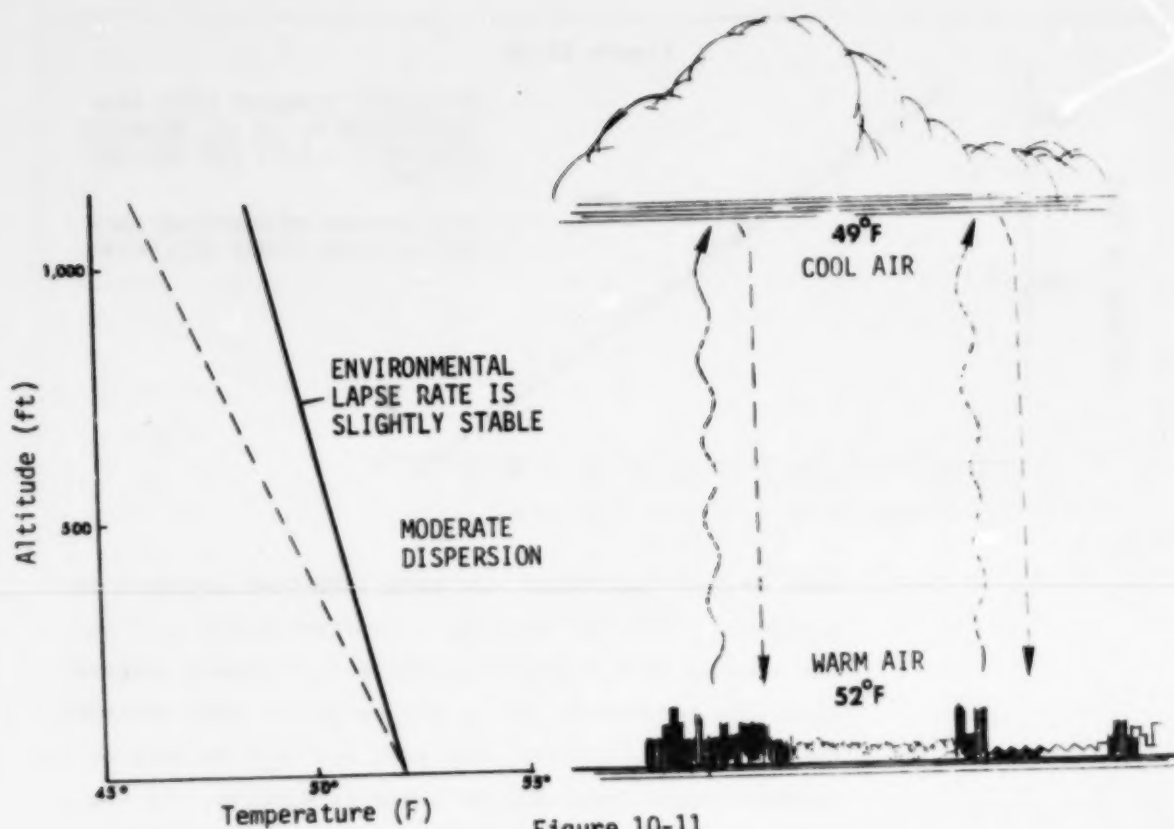


Figure 10-11

Consider Figure 10-12. This shows what happens as the sun sets on a clear day. The ground will begin to cool off rapidly, much more rapidly than the air above it. A layer of cool air will form near the ground. As the night continues, the cool layer of air will extend further into the atmosphere. Pollutants emitted into this cool air will remain near the surface of the earth, since they are essentially trapped under the warm layer of air into which they cannot rise. This condition is called an inversion, since the normal temperature structure is inverted. When the sun rises again on such a clear day, the solar radiation will quickly heat the surface of the earth, warming the layer of air in contact with it. This

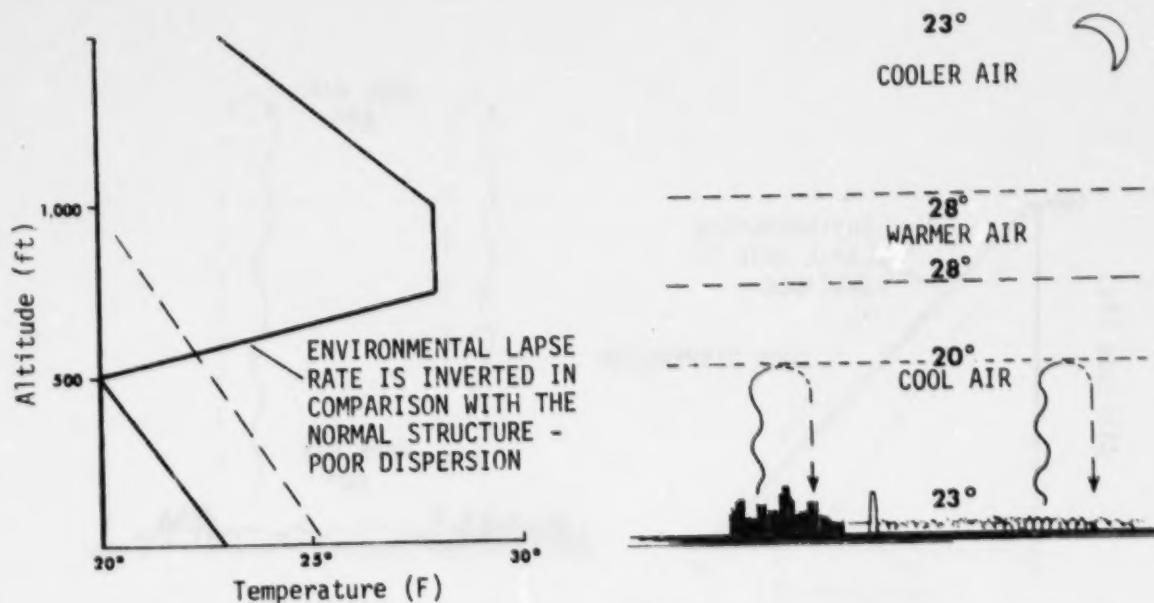


Figure 10-12

10

warm air will mix with cool air aloft, soon eliminating the cold inversion layer. Usually within two or three hours after sunrise, we will have returned to the unstable temperature structure as shown in Figure 10-13. In such unstable atmospheric conditions, good vertical mixing will occur. This cycle may be altered by stirring of the atmosphere with high winds, or by presence of clouds or precipitation, which will make both daytime mixing and nighttime inversions less extreme.

We can watch a plume or stream of smoke emitted from a large source of pollution and observe its behavior to determine whether conditions are stable or unstable. Figure 10-15 illustrates three of these plume types. When we have very unstable conditions, there is a great deal of mixing and overturning in the atmosphere. The plume in this case will take the shape of the overturning eddies, and will form what we call a "looping"

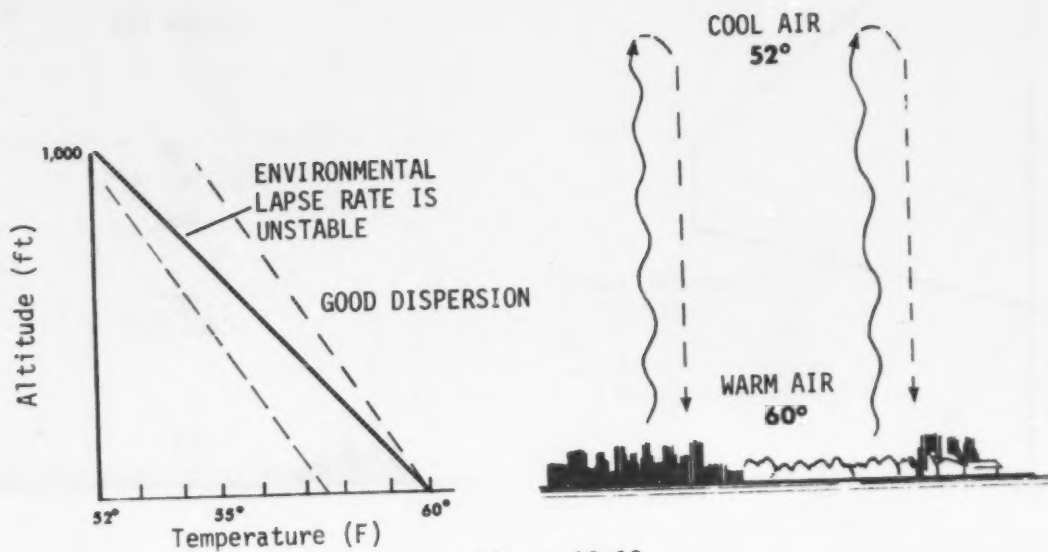


Figure 10-13

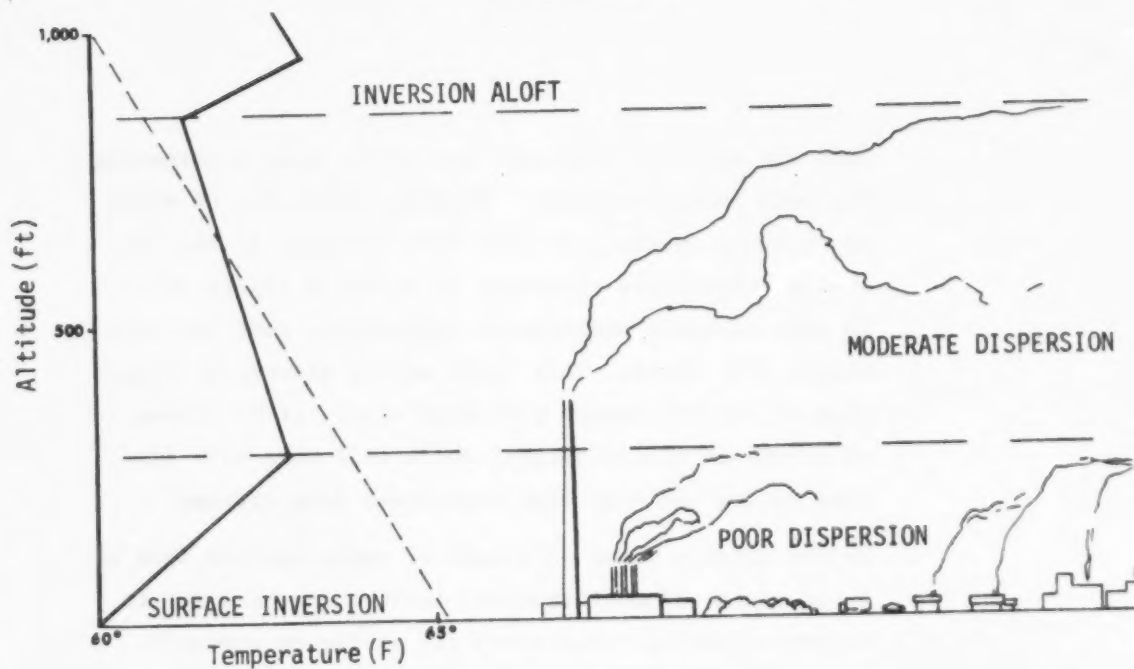


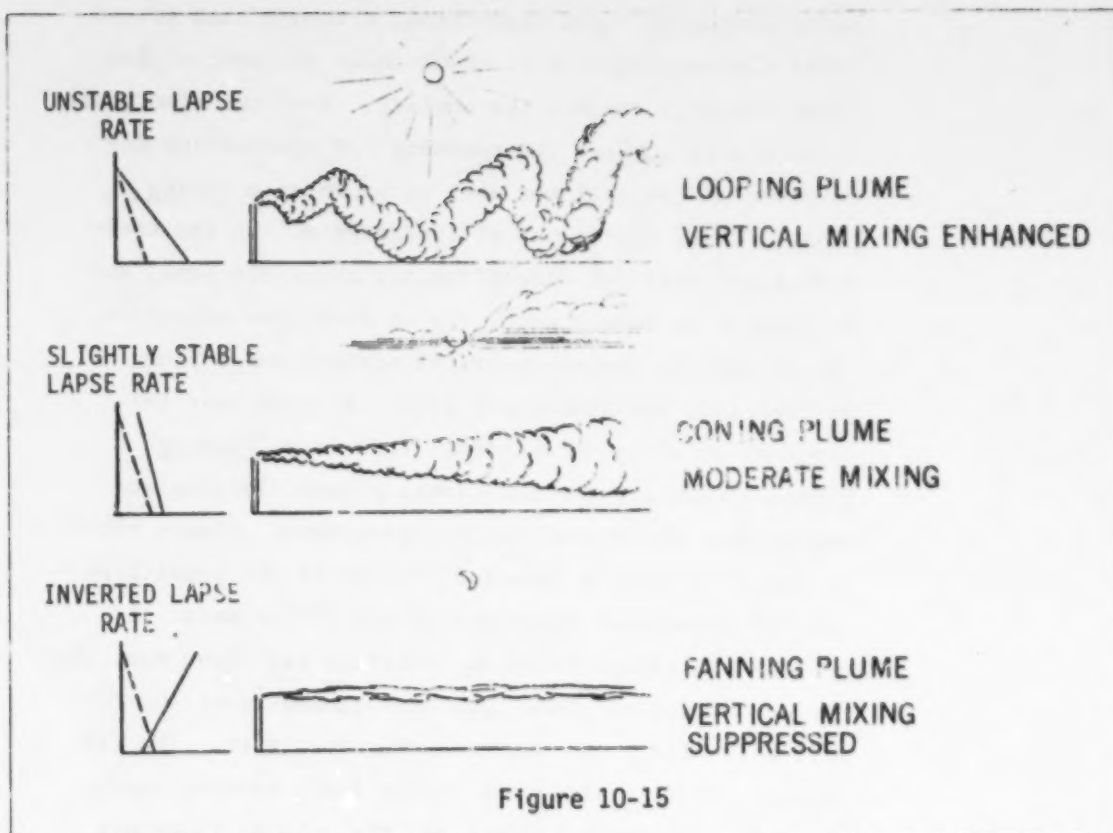
Figure 10-14

← DASHED LINE REPRESENTS "STANDARD" LAPSE RATE (REFERRED TO AS THE DRY ADIABATIC LAPSE RATE) - 5.4°F PER 1000 FEET ALTITUDE.
 ← SOLID LINE REPRESENTS THE ENVIRONMENTAL LAPSE RATE.

plume. This will result, as you would expect, in very rapid mixing and good dispersion, although high ground-level concentrations will result near the source when a plume actually reaches the surface. When the atmosphere becomes more stable, the tendency for overturning decreases, and we will see what is known as a coning plume. Here, the amount of spreading out in the horizontal and vertical directions are about the same, and dispersion is fairly good. In an inversion situation, the atmosphere resists vertical mixing, and a plume emitted into the atmosphere will stay very near the level at which it is emitted. This is a "fanning" plume. There are two additional plumes, lofting and fumigation, which are not discussed here. Please refer to Table 10-2 for a detailed outline of the conditions and the associated behaviors of the five plumes. As depicted in Figure 10-14 an inversion can occur near the surface or aloft. Emissions from ground-level sources will stay within the surface inversion layer. (We frequently see this situation in the early morning hours, when there is heavy traffic and the exhaust fumes are trapped in a surface inversion).

A high stack is an advantage in an area where there are frequent surface inversions, since pollutants emitted above the inversion level will stay at that level, and ground-level concentrations from that source will generally be minimal. With a little practice, you can learn the trick of judging the dispersion capacity of the atmosphere by watching the behavior of plumes.

Meteorologists use a concept called mixing depth, or mixing height to quantitatively represent the dispersion capacity of the atmosphere. Mixing height simply refers to the height to which vigorous vertical mixing takes place. Meteorologists have devised a method of



forecasting the maximum mixing height which can be expected on a given day, so that they can anticipate whether or not high concentrations of pollutants are likely to occur.

Figure 10-16 shows two different mixing heights. If the same emissions of pollutants were found in both situations, you would expect a much higher concentration of pollutants in the second instance, since there is a smaller volume within which the pollutants can be diluted. There are significant differences in the seasonal averages for mixing height at most locations. During the summer daylight hours, the mixing height may extend up to several thousand feet. In the winter, when less heat is received from the sun, the mixing height may be as low as a few

Table 10-2

PLUME BEHAVIOR AND RELATED WEATHER

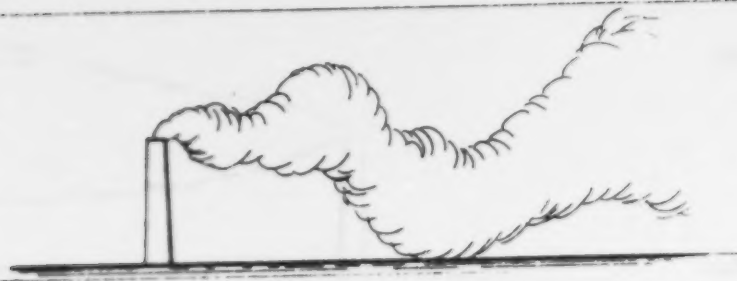
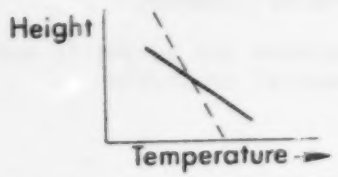
LOOPING	
Description	Irregular loops and waves with random sinuous movements; dissipates in patches; relatively rapid with distance.
Temperature Profile - Stability	Adiabatic or super-adiabatic lapse rate - unstable. 
Typical Occurrence	During daytime with clear or partly cloudy skies and intense solar heating; not favored by layer-type cloudiness, snow cover or strong winds.
Associated Wind and Turbulence	Light winds with intense thermal turbulence.
Dispersion and Ground Contact	Disperses rapidly with distance; large probability of high concentrations sporadically at ground relatively close to stack.
Ground Level Patterns	

Table 10-2 (continued)

CONING

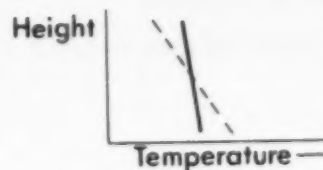
Description

Roughly cone-shaped with horizontal axis; dissipates farther down-wind than looping plume.



Temperature Profile - Stability

Lapse rate between dry adiabatic and isothermal-neutral or stable.



Typical Occurrence

During windy conditions, day or night; layer-type cloudiness favored in day; may also occur briefly in a gust during looping.

Associated Wind and Turbulence

Moderate to strong winds; turbulence largely mechanical rather than thermal.

Dispersion and Ground Contact

Disperses less rapidly with distance than looping plume, large probability of ground contact some distance downwind; concentration less but persisting longer than that of looping.

Ground Level Patterns

Top view
of Stack



Table 10-2 (continued)

FANNING



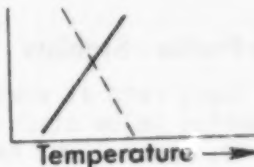
Description

Narrow horizontal fan; little or no vertical spreading; if stack is high, resembles a meandering river, widening but not thickening as it moves along; may be seen miles downwind; if effluent is warm, plume rises slowly, then drifts horizontally.

Temperature Profile - Stability

Inverted or isothermal lapse rate - very stable

Height



Typical Occurrence

At night and in early morning, any season; usually associated with inversion layer(s); favored by light winds, clear skies and snow cover.

Associated Wind and Turbulence

Light winds; very little turbulence.

Dispersion and Ground Contact

Disperses slowly; concentration aloft high at relatively great distance down wind; small probability of ground contact, though increase in turbulence can result in ground contact; high ground level concentrations may occur if stack is short or if plume moves to more irregular terrain.

Table 10-2 (continued)

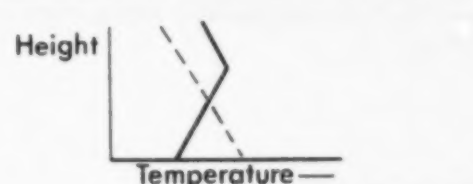
LOFTING Description Loops or cone with well defined bottom and poorly defined, diffuse top.	 A diagram showing a smoke plume rising from a stack. The plume has a well-defined, narrow base at the stack and then spreads out into a wide, diffuse, cone-like shape with a wavy, irregular top edge.
Temperature Profile - Stability Adiabatic lapse rate at stack top and above; inverted below stack--lower layer stable, upper layer neutral or unstable.	 A graph with 'Height' on the vertical axis and 'Temperature' on the horizontal axis. A dashed line represents the adiabatic lapse rate, sloping downwards from left to right. A solid line represents the actual temperature profile: it starts at a low point on the left, rises steeply to a peak (inversion) just above the stack height, and then follows the dashed line (lapse rate) at higher altitudes.
Typical Occurrence During change from lapse to inversion condition; usually near sunset on fair days; lasts about an hour but may persist through night.	
Associated Wind and Turbulence Moderate winds and considerable turbulence aloft; very light winds and little or no turbulence in layer below.	
Dispersion and Ground Contact Probability of ground contact small unless inversion layer is shallow and stack is short; concentration high with contact, but contact usually prevented by stability of inversion layer; considered best condition for dispersion since pollutants are dispersed in upper air with small probability of ground contact.	

Table 10-2 (continued)

FUMIGATION

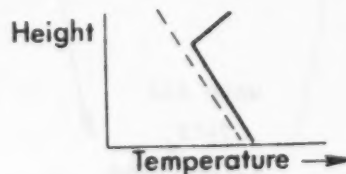
Description



Fan or cone with well defined top and ragged or diffuse bottom.

Temperature Profile - Stability

Adiabatic or super-adiabatic lapse rate at stack top and below; isothermal or inverted lapse rate above - lower layer unstable or neutral, upper layer stable.



Typical Occurrence

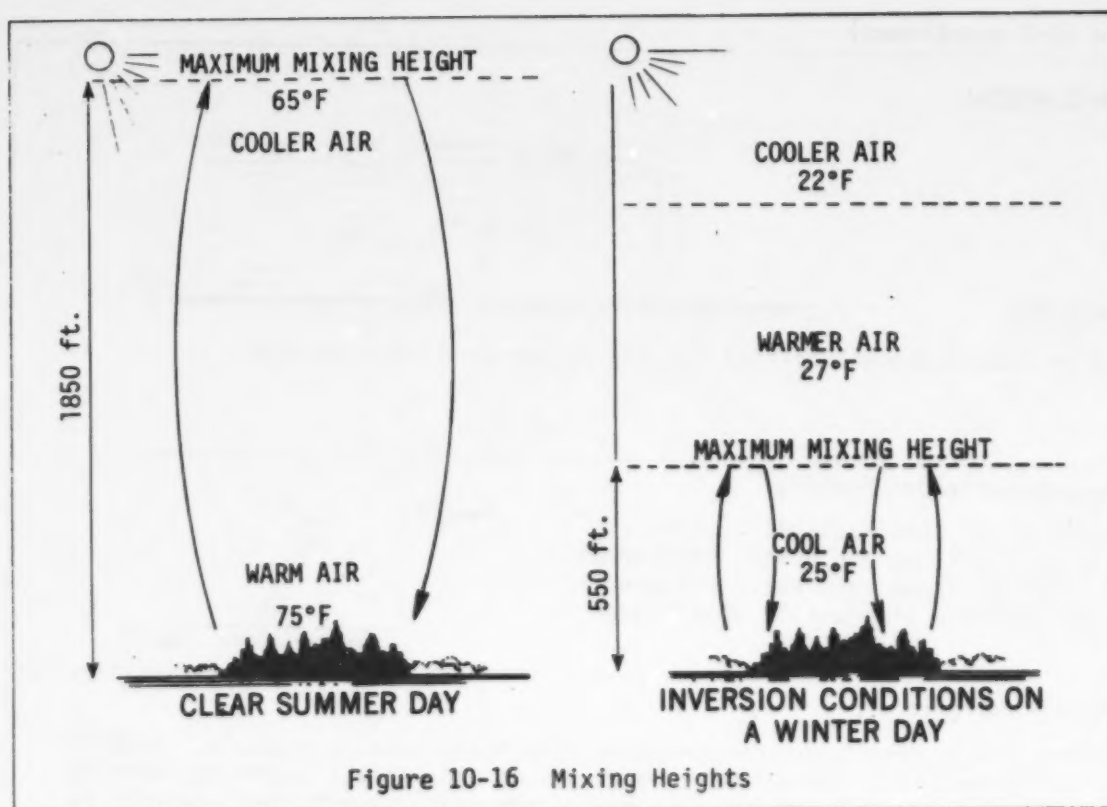
During change from inversion to lapse condition; usually nocturnal inversion is being broken up through warming of ground and surface layers by morning sun; breakup commonly begins near ground and works upward, less rapidly in winter than in summer; may also occur with sea breeze in late morning or early afternoon.

Associated Wind and Turbulence

Winds light to moderate aloft, and light below; thermal turbulence in lower layer, little turbulence in upper layer.

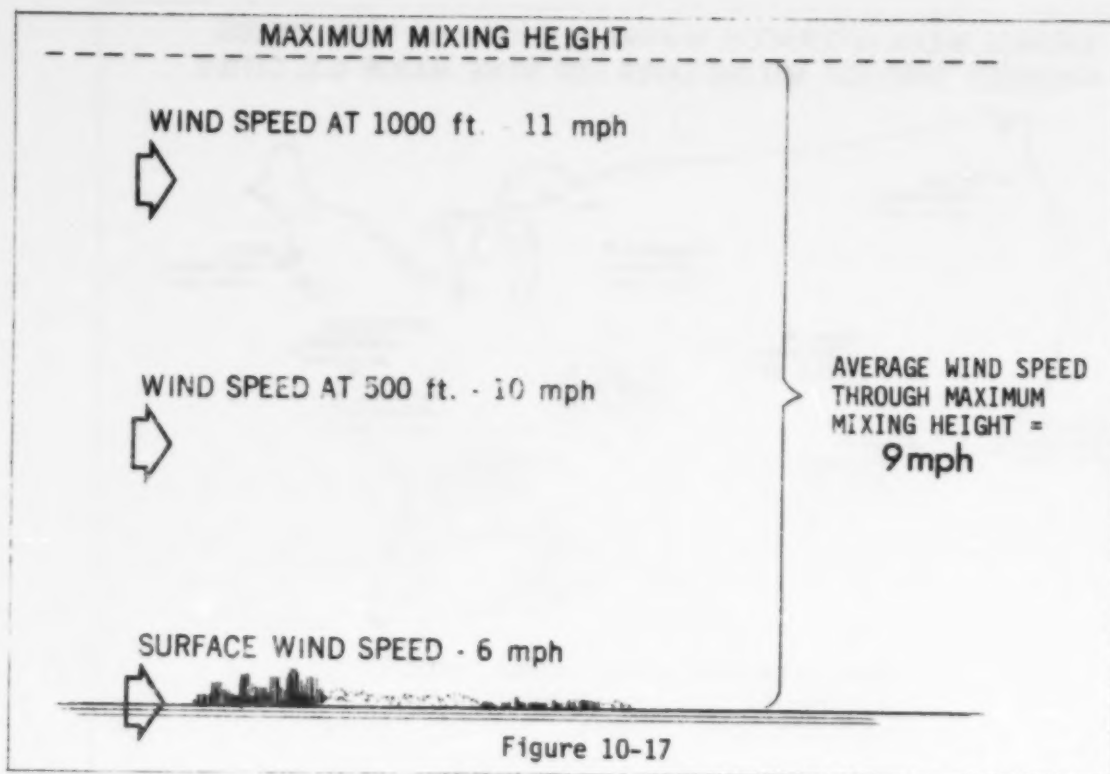
Dispersion and Ground Contact

Large probability of ground contact in relatively high concentration, especially after plume has stagnated aloft.



hundred feet. The mixing height will also vary in the course of a day. Morning and afternoon mixing heights are calculated each day for the major weather stations around the country. The mean, or average, wind speed through the mixing depth is also calculated (Figure 10-17). When these two critical meteorological parameters are considered, we have information about both horizontal and vertical motion, and we get a very good picture of the kind of dispersion which will occur.

The map in Figure 10-18 shows the average annual afternoon mixing heights and the corresponding annual wind speed averages for some of the major cities in the country.



You can see that for Phoenix there is an average annual afternoon mixing height of about 2400 meters, while for Boston the average is about 1000 meters. The average wind speed through this mixing depth is about 6 meters/second, or 13 mph, in Phoenix, while it is 8 meters/second, or about 18 mph over Boston. You can convert the rest of these figures to feet of mixing height and wind speed in mph by using the approximate conversion formulas and the table given in Figure 10-18. You will find that in meteorology, as in many of the sciences, both metric and the more familiar British units of measurements are used. It will help you to become familiar with both of these, and to learn a few of the simple rules for conversion.

**AVERAGE MEAN AFTERNOON MIXING HEIGHTS AND WIND SPEEDS
AVERAGED THROUGH MIXING LAYER FOR SOME MAJOR U.S. CITIES**



Mean afternoon mixing height, annual
average to convert: 1 meter =
approximately 3.3 feet

Mean annual wind speed averaged
through the afternoon mixing
layer to convert: 1 m. sec⁻¹ =
approximately 2.2 mph

EQUIVALENT UNITS OF MEASURE USED IN METEOROLOGY

LENGTH, DISTANCE	1 meter	=	39.37 inches
			1.094 yards
	0.305 meter	=	1 foot
	0.914 meter	=	1 yard
VELOCITY (WIND SPEED)	1 meter per second	=	2.2 miles per hour
	(m.sec ⁻¹ or m/sec)		(mi. hr. ⁻¹ or mi/hr)
TEMPERATURE	0°centigrade	=	32° Fahrenheit
	(freezing point of water)		
	100°centigrade	=	212° Fahrenheit
	(boiling point of water)		
	to convert C = (5/9)(F-32) F=(9/5) (C+32)		
PRESSURE (BAROMETRIC PRESSURE)	1 millibar	=	.0295 inches mercury
	1 inch mercury	=	33.9 millibars
	1013.25 mb.Hg.	=	29.9 in.Hg.
	(pressure at sea level)		

Figure 10-18

The information given on the map in Figure 10-18 does not tell the whole story about dispersion capacity over these cities, since these are annual averages. However, by studying data of this sort, about vertical and horizontal movement and especially by looking at patterns of daily and seasonal variation and the implications for dispersion of pollutants, meteorologists have identified some areas of the country where we should recommend against extensive urban development. These areas, where weather conditions simply do not favor the dispersion of pollutants, include Oregon and central California, the great basin in the Rocky Mountains, northern Minnesota, and the area around and including West Virginia.

We have examined in some detail the two meteorological factors that are of primary concern in air pollution dispersion. Let us look briefly at a few other factors that can be important in local or specific situations.

Solar Radiation, Precipitation, and Humidity

10.7. Solar radiation is important in the formation of photochemical oxidants, since it plays a vital role in the interaction of nitrogen oxides and hydrocarbons emitted from automobiles and some industrial plants. Sunshine becomes a meteorologically important factor, especially in urban areas on the west coast and in the Rocky Mountain area, where there are a great many days each year with clear skies. Precipitation and humidity can also play an important role, affecting both the dispersion and formation of pollutants. Precipitation acts as a natural cleansing process, washing particles out of the air. In this sense, precipitation is advantageous, but when there is rain, fog, or high humidity in the air, there is also the potential for the conversion of some gaseous pollutants into more potent forms. One prime example

is the conversion of sulfur dioxide into sulfuric acid, which acts to corrode metals and to damage building materials. The acidity of rain in many urbanized areas has increased significantly in recent years as a result of absorption of air pollutants.

Topography

10.8. Topography affects the meteorological factors, and thus, affects the dispersion of pollutants. Local air pollution problems are often related to the effect that topography has on the ability of the atmosphere to mix pollutants. Figure 10-19 illustrates some of these problems. Los Angeles and other coastal areas are plagued by a combination of land and sea breezes and encircling mountain ranges, together with a low mixing height and transport wind speed which act to trap pollutants and cause their accumulation. Emissions from sources located in mountain valleys or river basins will be trapped by topographical features, especially at night or in the early morning. Even minor features of the landscape, such as hills, small bodies of water, or a parking lot, can modify the microscale wind flow and turbulence, significantly affecting pollutant dispersion. So, we can add topography to our list of factors affecting the formation and dispersion of pollutants.

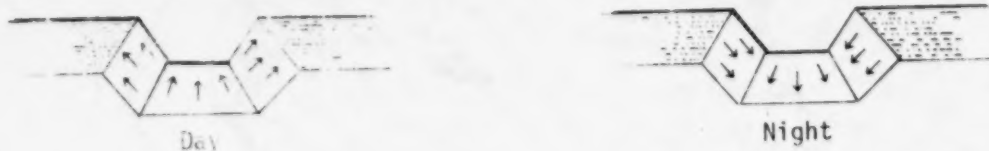
Sky Condition

10.9. Sky condition is another reportable meteorological element that can help make the total visible emission observation process more complete and credible. Clouds and obscuring phenomena like haze, smoke, or rain definitely affect the contrast between the plume and background as does the elevation of the sun and the location of the observer with respect to the plume.

A SEA BREEZE WILL PREVAIL ALONG A LAKE OR SEACOAST DURING THE DAY. A LAND BREEZE IS MORE COMMON AT NIGHT. THIS CYCLE, TOO, CAN CAUSE POLLUTANT CONCENTRATIONS TO RECUR IN URBAN AREAS



WINDS WILL TEND TO FLOW OUT OF A VALLEY IN THE DAYTIME, AND DOWN INTO THE VALLEY AT NIGHT, SOMETIMES CAUSING A 'RECYCLING' OF POLLUTANTS



UNEVEN TERRAIN WILL CAUSE MECHANICAL TURBULENCE IN THE WIND



MINOR FEATURES, SUCH AS PARKING LOTS, BUILDINGS, OR VEGETATION, CAN AFFECT DISPERSION OF POLLUTANTS



Figure 10-19 Topography affects weather circulation and dispersion of pollutants.



SPECIMEN STATION MODEL

Wind speed: (21 to 25 miles per hour)

Direction of wind (From the north west)

Temperature in degrees Fahrenheit

Total amount of clouds (Sky completely covered)

Visibility (1/2 miles)

Present weather (Occasional slight snow in flakes)

Dewpoint in degrees Fahrenheit

Cloud type (Low fractostratus and/or fractocumulus)

Height of cloud base (1300 to 599 feet)

Barometric pressure at two level: Initial 9 or 10 omitted (1024.7 millibars)

Barometric change in past 3 hours (in tenths of millibars)

Barometric tendency in past 3 hours (Rising)

Sign showing whether pressure is higher or lower than 3 hours ago

Time precipitation began or ended (Began 3 to 4 hours ago)

Weather in past 6 hours (Rain)

Amount of precipitation in last 6 hours

Partly okay covered by lowest cloud (Seven or eight tenths)

Abridged from W M O Code

10-30

The National Weather Service has very explicit rules for determining sky condition, most of which are too technical to be discussed in detail here. Usually most air pollution inspectors are only required to specify the total cloud cover according to one of four categories, i.e. clear, scattered, broken, or overcast, depending on the number of tenths of the entire sky covered by cloud layers. Inspectors/smoke readers should also be able to determine total cloud cover at a given station on a national weather map such as in Figure 10-20.

A complete evaluation of sky condition includes the type of clouds or obscuring phenomena present, their stratification, amount, opacity, direction of movement, height of bases and the effect on vertical visibility of surface-based obscuring phenomena. Much of this information can also be gleaned from the plotted station data in Figure 10-20. However, this detail is not required on smoke reading forms.

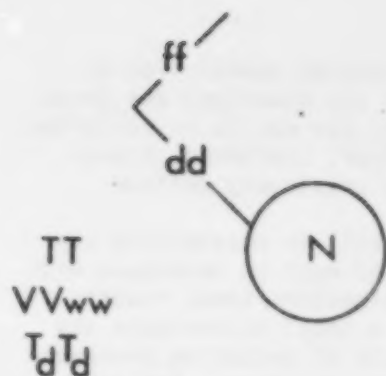
A few definitions are in order, taken from the GPO Publications: "Manual of Surface Observations (WBAN),"

Circular N, 7th Ed. (Rev.) 1966 with changes to May 1969 (now out of print) and; Federal Meteorological Handbook No. 1, "Surface Observations," April, 1970.

1. Sky Cover. A term used to denote the amount (to the nearest tenth) of the sky which is:
 - (a) Covered but not necessarily hidden by clouds and/or obscuring phenomena aloft
 - (b) Hidden by surface-bases obscuring phenomena,
or
 - (c) Covered or hidden by a combination of a or b.

2. Total Amount of Sky Cover. The amount of tenths of the entire sky that is covered, but not necessarily hidden, by all layers present. This amount cannot be greater than 1.0 (10/10).
3. Horizon. The actual lower boundary (local horizon) of the observed sky or the upper outline of terrestrial objects including nearby natural obstructions. It is the distant line along which the earth, or the water surface at sea, and the sky appear to meet. The local horizon is based on the best practical point of observation near the earth's surface and selected to minimize obstruction by nearby buildings, towers, etc.
4. Transparent Sky Cover. Those portions of cloud layers or obscurations which do not hide the sky. Blue sky or higher clouds can be discerned through these portions during daylight, and the moon and brighter stars may be discerned at night.
5. Opaque Sky Cover. Those portions of cloud layers or obscurations which hide the sky and/or higher clouds. Translucent sky cover that hides the sun and moon (not stars) may be dimly visible will be considered as opaque.
6. Sky Cover Amounts. Sky cover amounts are evaluated:
 - (a) In terms of the entire sky area above the local (apparent), rather than celestial horizon.
 - (b) In tenths of the sky covered for aviation observations and national weather map plotting.
 - (c) In terms of the amount of sky covered or hidden.
 - (d) With reference to an observer on the earth's surface.

The sky cover symbols, together with their meaning, teletype contraction, and brief explanation are given in Table 10-3, from "Circular N", referred to above. To assist you in determining total sky cover from surface weather maps, remember the basic plotting model where:



dd = wind direction
 ff = wind speed
 TT = surface temperature
 $T_d T_d$ = dew point temperature
 VV = surface visibility
 ww = present weather
 N = sky coverage (total amount)

Table 10-3 Sky Cover Symbols

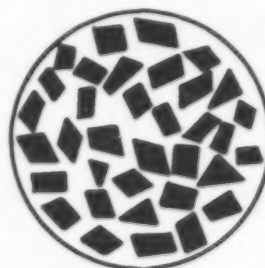
Symbol	Meaning & Contraction	Explanation ¹
○	Clear <u>CLR</u>	0.0 total sky cover. (This symbol is used alone - not in combination with others.)
⊙	Scattered Layer Aloft <u>SCTD</u>	0.1 to 0.5 sky cover at and below level of layer aloft and not classified as "thin".
⊗	Broken Layer Aloft <u>BRKN</u>	0.6 to 0.9 sky cover at and below level of layer aloft and not classified as "thin".
⊕ ²	Overcast Layer Aloft <u>OVC</u>	1.0 (ten tenths) sky cover at and below level of layer aloft and not classified as "thin".
X	Obscuration (Surface Layer)	All of sky is hidden by a surface-based layer, ³ i.e., vertical visibility is restricted by the layer.
-X	Partial Obscuration (Surface Layer)	0.1 or more, but not all of sky is hidden by surface-based layer, i.e., vertical visibility through the layer is not completely restricted.
-⊙	THIN <u>SCTD</u>	Transparent sky cover comprises 1/2 or more of the total sky cover. Ref. definition of transparent sky cover.
-⊗	THIN <u>BRKN</u>	
-⊕	THIN <u>OVC</u>	

N	SKY COVERAGE (Total Amount)
	No clouds
	Less than one-tenth or one-tenth
	Two-tenths or three-tenths
	Four-tenths
	Five-tenths
	Six-tenths
	Seven-tenths or eight-tenths
	Nine-tenths or overcast with openings
	Completely overcast
	Sky obscured

Figure 10-21

The map plotting symbols for N, total amount of sky coverage, are shown in Figure 21 and can easily be converted to the terms clear, scattered, broken, and overcast as previously defined.

Observer skill in determining sky condition can and must be developed with practice and inspectors/smoke readers should make it a habit to evaluate sky cover and effects of obscuring phenomena whenever they are outdoors. For example, if the circle represents the horizon in the figure below, what is your initial estimate of the sky cover?



The correct answer is 5/10 or scattered cloud cover. Remember, 6/10 of the sky, rounded to the nearest tenth, must be covered with clouds to be termed broken.

- (a) Determine amounts to the nearest tenth, i.e., if amount present is judged to be zero rather than one tenth, it will be reported as clear .
- (b) The symbol  is used in combination with other lower overcast symbols

in Col. 3 only when such lower over-
case layers are classified as thin,
i.e., reported as $-\oplus$.

(c) Note that when more than 9/10 of the
sky, but not all of the sky, is hidden
by obscuring phenomena, and:

- (1) When the sky overhead is obscured,
report the condition as an obscura-
tion "X".
- (2) When it is not so obscured, e.g., a
homogeneous layer, report the condi-
tion as partial obscuration, "-X".
- (3) Report the direction of discontinui-
ties or breaks, as remarks, e.g., THIN
FOG NW, or BREAK IN F TO NW.

CHAPTER XI.
LEGAL ASPECTS OF
VISIBLE EMISSIONS

History and Test Cases

11.1. Law may be divided into two categories - common law and statute law.

11.2. Early air pollution laws fell under the category of prohibiting smoke as a common nuisance or a public nuisance. Under these common law nuisance regulations it had to be proven in each individual case that the smoke was injurious or offensive to the senses. In the case of a public nuisance, it had to be proven that a large number of persons were affected.

11.3. In modern times, smoke and air pollution came to be regarded as an absolute nuisance (a nuisance per se) and a state could pass a statute that declared the emission of dense black smoke to be illegal. Injury did not have to be proven in each case.

11.4. The State may grant to a city, county, or other local government the power to pass ordinances regulating air pollution. The State can later cancel the powers which they granted earlier. The Federal government can also regulate air pollution in certain instances.

11.5. This power to regulate air pollution is given to the States by the Tenth Amendment of the Constitution, which states: "The powers not delegated to the United States by the Constitution nor prohibited by it to the States are reserved to the States respectively, or to the people."

11.6. The only constitutional limitation to how far the State's air pollution control law can go is in the Fourteenth Amendment to the Constitution: "...nor shall any State deprive any person of life, liberty or property, without due process of law, nor deny to any person within its jurisdiction the equal protection of the laws."

Most of the air pollution cases that are appealed test the constitutionality of the control ordinance by means of the "due process" clause or the "equal protection" clause.

11.7. Once black smoke had been declared illegal, laws were needed to limit the emission by setting maximum permissible pollution standards, or regulating the use and operation of equipment and fuels.

11.8. Examples of maximum permissible emission standards are the Ringelmann Standard and the Equivalent Opacity Standard.

11.9. In 1910 the Ringelmann Chart was first recognized legally in the United States by its inclusion in a smoke ordinance for Boston passed by the Massachusetts Legislature.

11.10. The constitutionality of the Los Angeles County rule that provides standards for reading of densities and opacities of visible emission (L.A. County Rule 50 or Section 24242 of the California Health and Safety Code) has been tested twice, in 1951 and in 1955. In both of these cases its constitutionality was upheld by the Los Angeles Superior Court. In 1955 an appeal of the Superior Court's decision to the United States Supreme Court was dismissed by the Supreme Court.

11.11. When first adopted, Section 24242 stated: "A person shall not discharge into the atmosphere from any single source of emission whatsoever any air contaminant

for a period or periods aggregating more than three minutes in any one hour which is

- (a) As dark or darker in shade as that designated as No. 2 on the Ringelmann Chart as published by the United States Bureau of Mines, or
- (b) Of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in subsection (a) of this section."

11.12. The 1951 case, People Versus International Steel Corporation, dealt with subsection (a) of Rule 50. The 1951 Supreme Court dismissal directly concerned section (b) and involved four separate cases of smog

- (1) People Versus Plywood Manufacturers of California
- (2) People Versus Shell Oil Company
- (3) People Versus Union Oil Company
- (4) People Versus Southern California Edison Company

Other cases approving the use of the Ringelmann Chart include: Board of Health of Weehawken Township Versus New York Central Railroad (New Jersey, 1950), and Penn-Dixie Cement Corp. Versus City of Kingsport (Tennessee, 1949).

11.13. The California appeal cases established

- (a) That the Code is constitutional.
- (b) That it is permissible for a statute to adopt, for a description of a prohibited act, a publication of the United States Bureau of Mines.
- (c) That inspectors trained in the use of the Ringelmann Chart are experts.

They may testify as expert witnesses concerning the Ringelmann Number of a particular smoke emission without having had a chart in their possession while observing the plumes.

- (d) That the fact that the ordinary person is uncertain whether a smoke plume is as dark as Ringelmann No. 2 or whether its opacity equals that of smoke matching Ringelmann No. 2 is no reason for the unconstitutionality of the Rule.
- (e) That the drawing of a line between permission and prohibition (Ringelmann No. 2) is a matter of legislative discretion that will not be reversed by the Courts unless abused.
- (f) That if the plume, fairly viewed from any position, exceeds the regulation of Ringelmann shade, the smoke is in violation no matter how light the color may look to someone situated at another vantage point.

Equivalent Opacity and Smoke Emissions Law

11.14. Some requirements for a good air pollution law are:

- (a) It must have the power to reduce contamination.
- (b) It must be enforceable. It must be capable of being enforced uniformly and it should not be expensive to enforce.
- (c) It must be reasonable.
- (d) It must be clear and precise so that people can understand it and avoid breaking it.

(e) It is not necessary to prove that the owner of the stack had criminal intent in violating the ordinance, just the fact that his smoke is blacker than the allowed Ringelmann No. is sufficient.

(f) Any classification of sources it establishes must be reasonable. For example, an industry operates its stack for profit while a homeowner does not; therefore, different emission standards can be required of industrial and domestic chimneys.

11.15. As a practical matter, judges will weigh the equities in a case to determine which of the two parties will sustain the most injury. They would not put a large company out of business, but could require them to pay a fine or install a control device.

11.16. Smoke emissions and equivalent opacity regulations may restrict the shade of smoke to be no darker than a specified Ringelmann Number or a particular percent opacity, depending upon the source and the conditions.

11.17. The different sources regulated may be listed as fuel burning equipment, internal combustion engines, open fires, incinerators, railroad locomotives, and steamships. The restricted sources may also be described as stacks or vents or as any single source of emissions whatsoever.

11.18. Different restrictions may apply to incinerators and domestic installations.

11.19. Limitations may be set allowing smoke of a darker shade for several minutes of every hour during periods when a new fire is being built.

11.20. Exceptions may be granted for fires used in training firemen or on farms. There may also be exceptions for industrial accidents which cause black smoke or for special processes.

11.21. Codes may exclude plumes of uncombined water from the restrictions.

Local Regulations

11.22. The air pollution inspector must know and understand the visible emissions regulations that he will be enforcing.

How To Be An Expert Witness

- (1) Under ordinary circumstances the average citizen cannot testify as to his opinions or conclusions, but the expert witness can. The opinion of the expert witness helps the judge make his decision.
- (2) It is preferable to subpoena a witness, even a smoke inspector, to appear in court rather than to have him appear voluntarily. When the witness is subpoenaed, it demonstrates that he is not appearing in court just because he has a prejudiced opinion for or against one of the parties in the case.
- (3) Before appearing in court, prepare your materials and refresh your memory. An attorney

spends 2 to 10 hours in preparation for every hour in court. An expert witness should spend a comparable amount of time in reviewing his observations before he testifies.

- (4) As an expert witness the air pollution officer should not have to read his testimony. However he has a right to refer to his records and notes to refresh his memory.
- (5) Since the case may not appear in court until months after the violation occurred, the officer should complete his report fully at the time of violation.
- (6) If you take a picture of a plume, you should know what operation or process is going on in the plant at the time of the picture. Record the time, weather, film type, exposure setting, lens type, and distance from the plume.
- (7) Before having any telephone conversations with a plant operator, it is desirable to meet the man so that you can later identify his voice on the phone.
- (8) Investigate every case thoroughly. Do not become overconfident after you have appeared in court several times.
- (9) Behavior on the witness stand:
 - (a) Dress and act like an expert.
 - (b) Be responsive to the question that is asked you. Do not volunteer information about some unrelated topic or question.
 - (c) Take a second to frame your answer before giving it.
 - (d) If you hear "objection," quit talking.

- (e) If you make a mistake, admit it.
 - (f) If you cannot answer just "yes" or "no" to a question, say so.
 - (g) Keep calm. Don't lose your temper.
 - (h) Don't try to second guess your attorney.
- (10) You will be directly examined by your attorney and cross-examined by the opposing attorney. There can then be a redirect examination and a recross examination. You can also be recalled at a later time to clear up your testimony.
-

Suggested Additional Reading

Field Operations and Enforcement Manual for Air Pollution Control APTD-1100, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711 1972, available from National Technical Information Service, Springfield, VA 22151.

Environment Reporter, The Bureau of National Affairs, Inc., Washington, D.C.

CHAPTER XII.

OBSERVATION REPORTS FOR VIOLATIONS

12.1. The purpose of making a visual observation of the degree of blackness or whiteness of a plume is to determine if the source is in compliance with regulations.

12.2. To provide a sufficient basis for court prosecution, the inspector must gather evidence essential for a prima facie case -- that is, a case which unless contradicted adds up to a violation of the law.

12.3. Each and all of the elements of the violation must be proven or else there is no case to take to court. For instance, if the regulations states:

"A person, owner, agent, operator, firm or corporation shall not discharge into the atmosphere from any single source of emission whatsoever any air contaminant for a period or periods aggregating more than three minutes in any one hour which is as dark or darker in shade than that designated as No. 2 on the Ringelmann Chart..."

Then all of the following must be proven:

- (a) A person, owner, agent, operator, firm or corporation
- (b) Discharged
- (c) Into the atmosphere
- (d) From a single source
- (e) A contaminant
- (f) Of greater than No. 2 Ringelmann
- (g) For more than 3 minutes in 1 hour.

12.4. The report and the citation forms when filled out completely assure the inspector that he has collected the data essential for supporting a prosecution of a violation.

12.5. The written report is not in itself the evidence that is used to prove a case in court. Rather, the evidence compiled by an inspector consists of his expert opinion concerning the shade of the emissions he observed and his testimonial evidence given when he testifies to the facts surrounding his observations.

12.6. The written report may not actually appear in the court proceedings, but the inspector may use it to refresh his memory.

12.7. The facts that the inspector should record in his report of the observation include:

- (a) The nature and extent of the violation;
- (b) The time and location of the violation;
- (c) The person(s) responsible for the violation;
- (d) The equipment involved with the violation;
- (e) The operational or maintenance factors which caused the violation.

12.8. This information can be filed in two reports—a smoke observation report and a plant operation report. The latter would cover information identifying and describing the equipment that generated the plume and determining the factor(s) that caused the violation.

12.9. Either of the two reports might contain information concerning the names and addresses of the owners of the company and of the operators of the equipment as well as any remarks these people may have regarding the equipment.

12.10. The smoke observation portion of the report form should include spaces for the following supplementary information:

- (a) Direction or distance of the observer from the source;
- (b) Direction from which the wind was blowing and, possibly, the wind speed;
- (c) Weather conditions during the observation describing whether the sky was clear, overcast, scattered, or broken, and whether it was hazy or raining;
- (d) Date and time during which the observation was made;
- (e) Name and address of the firm where the observation was made;
- (f) Type of air contaminant;
- (g) Description of the source, such as number of stacks and their height;
- (h) Signature of the inspector.

12.11. The basic portion of the smoke observation report should record the visible emissions observed, showing the continuous time intervals for each density and opacity and color changes. The inspector should note to the nearest quarter minute the beginning and ending observation times for each change of density of color.

12.12. The total violation time for each hour of observation should be recorded as well as the total violation time during the entire period of observation.

12.13. A photograph of the source can be taken before or after, but not during the observation. Photographs

do not always give a true reproduction of plume color.

12.14. Since the accuracy of reading visible emissions is within 7.5% opacity, it is suggested that a violation notice not be issued to the owner of the equipment unless it is in violation for 1 minute longer than the legal limit and for 1/2 Ringelmann or 10 percent opacity greater than the legal limit.

Special Designations

12.15. In some state, county, and municipal visible emissions regulations, special source categories or specific sources are named. Some of these include

- (a) Fuel-burning equipment
- (b) Combustion equipment
- (c) Apartment houses
- (d) Office buildings
- (e) Schools
- (f) Hotels
- (g) Hospitals
- (h) Process equipment
- (i) Motor vehicles
- (j) Internal combustion engines
- (k) Diesel motor vehicles
- (l) Railroads
- (m) Steamships
- (n) Incinerators
- (o) Open fires

12.16. Emissions from incinerators are often required not to exceed a Ringelmann No. 1 or an equivalent opacity of 20 percent although the limit for other sources may be No. 2 Ringelmann. Some state implementation plans have reduced opacity standards to 20% or less.

12.17. Some ordinances and regulations grant exceptions to the visible emissions regulations. A few of these are:

- (a) Smoke may attain densities as high as No. 3 for an aggregate of 3 minutes in any 15 consecutive minutes when a new fire is being built, a fire box is being cleaned, tubes are being blown, or an equipment breakdown occurs. (Regulations may vary on the time allowed. Other codes include 3 minutes in a 30-minute period, 12 minutes in a 24-hour period, etc.)
- (b) Smoke from railroad locomotives or steamships may attain values as high as No. 3 Ringelmann for a limited number of minutes during periods ranging from 6 minutes to 8 hours.
- (c) In some localities, exceptions to visible emission regulations may be granted to certain industrial operations. Some examples from one State's code are
 - (1) Transfer of molten metals;
 - (2) Emissions from transfer ladles;
 - (3) Coke ovens when pushing coke after discharge from the ovens;
 - (4) Water quenching of coke after discharge from the ovens;
 - (5) Gray iron cupola furnaces.

Suggested Additional Reading

"Guidelines for Evaluation of Visible Emissions" - EPA-340/1-75-007, April 1975, National Technical Information Service, Springfield, VA 22161

CHAPTER XIII.

EMISSION GENERATOR

13.1. For use in training personnel to read smoke, it is necessary to have a device that will produce both black smoke and white smoke plus an instrument to measure the opaqueness of the smoke that is produced.

13.2. Smoke-generating devices have been built by some air-pollution control agencies for their use. The principles of operation of all these units are similar. Other agencies have purchased manufactured generators.

Mark II Smoke Generator

13.3. The Mark II Smoke Observers Training Unit, manufactured by Environmental Specialties, is the most widely used smoke generating unit. It is portable and each unit is custom made; however, the principal features of the Mark II are present in all models.

Black Smoke

13.4. When a carbon-containing fuel is burned with insufficient air, a smoky flue gas is produced. The smoke consists of partially burned carbon particulates suspended in the gas.

13.5. In the smoke generator, black smoke is created by burning toluene with a deficiency of oxygen. (Diesel fuel is used by some generator operators.) This fuel is burned in a furnace that consists of a 12-cubic-foot steel combustion chamber lined with refractory bricks. The combustion air entering this chamber is limited.

The toluene flow into the furnace is controlled by a fine metering valve. The density of the black smoke is varied by using this valve to adjust the rate of fuel injection through a nozzle into the combustion chamber. Note: Toluene has replaced benzene. Benzene has been placed on the toxic substance list.

White Smoke

13.6. To produce the white smoke, No. 2 fuel oil (the grade usually used for home or commercial heating) is vaporized. This vapor is then condensed into an aerosol cloud of a white color. The opacity of this cloud is controlled by adjusting the flow of the No. 2 fuel oil.

13.7. In the Mark II, the white aerosol vapor is created by injecting the fuel oil through a hypodermic needle into the manifold carrying the hot exhaust from a small lawnmower-sized gasoline engine. This engine runs a generator that can provide electric power for the Mark II unit. Considerable heat is required for vaporizing the fuel oil. Sufficient heat is provided by operating the generator under an appreciable load.

13.8. In the production of both black and white smoke, the smoke is diluted with ambient air before it enters the stack. The degree of dilution is controlled by dampers in the air inlet to the induced draft blower fan.

Transmissometer

13.9. The opaqueness of the white or black smoke is measured by a transmissometer located in a 4-foot length of pipe mounted perpendicular to the smoke stack at a point 6 feet below the top of the stack. The opaqueness

measurement from the transmissometer can be read by the generator operator on a scale divided into Ringelmann Numbers and equivalent opacity percentages. The transmissometer reading serves as the standard with which the smoke reader compares his visual observations.

13.10. The transmissometer for the Mark II is a simple light source and photocell combination. The light source may be a flashlight bulb or automobile taillight bulb mounted in a silvered reflector that concentrates the light into a beam that is aimed at the photocell 4 feet away. The photocell has a special sensitivity closely approximating the standard spectral-luminosity curve for photopic vision.

13.11. One foot of the path length of the beam is through the stack of the generator. In this portion of the path the intensity of the light is reduced in proportion to the amount of smoke being produced by the generator. This smoke is prevented from entering the remaining 3 feet of the transmissometer path by circular smoke stops that reduce the diameter of the transmissometer pipe. In addition, these 3 feet of the transmissometer path are continually flushed with outside air by two fans, one mounted at each end of the pipe.

13.12. The combination of smoke stops and ambient air flushing ensures that there will be no smoke buildup in the pipe. As a result, the only obstruction to the light beam occurs when the beam passes through the 1-foot-diameter stack.

13.13. The percent transmission of light that reaches the photocell is relayed electrically to the operator's station. Here, it may be read from the dial of a micro-ammeter or from a pen trace on a recorder depending upon which of these devices is supplied with the generator unit.

13.14. The transmissometer system is calibrated from 100 percent to zero transmission (zero to #5 Ringelmann and zero to 100 percent equivalent opacity) by inserting several grades of neutral density filters into the light path between the bulb and the photocell and adjusting the microammeter or recorder for the percent of light transmitted.

Conduct of the School

13.15. The smoke reader's training on the smoke generator begins with a familiarization series of black and white smoke densities. Upon the sound of the horn, the instructor calls out the meter or recorder reading of Ringelmann Number or equivalent opacity.

13.16. After this familiarization period the students go through a practice run of 25 shades of black and 25 shades of white smoke. Each reading is made by the student at the sound of the horn and entered on his training form just as he will do it later when he is reading for qualification.

13.17. Following the practice run the students will begin their qualification runs of 25 white and 25 black shades.

13.18. In between qualification runs the generator operator may conduct short series of familiarization review runs for the benefit of the students.

Other Smoke Generating Equipment

13.19. Los Angeles - 1962

(a) Black Smoke System

The oil burner is a modified mechanical pressure atomizing type. The combustion

chamber is a 40-cubic-foot-rectangular steel box lined with 6 inches of refractory fire clay. The various degrees of incomplete combustion of the fuel are obtained by adjusting the fuel flow. The smoke from the combustion chamber passes along a horizontal duct into a cooling chamber and then into the stack. A forced-draft fan discharges ambient dilution air into the base of the stack and pushes the smoke up the stack. This forced draft helps to prevent distortion of the plume by the wind as the smoke exits from the stack. The cooling chamber prevents secondary combustion from occurring at the base of the stack as the combustion products are diluted with air.

(b) White Smoke System

The "white smoke" is created by spraying a distillate type of oil into a chamber where it is vaporized by the heat generated in an adjacent heating chamber. The vapor is forced up the stack by a forced draft fan that pumps in dilution air. The vapor is condensed into a white cloud of aerosols. The operator controls the opacity of the plume by adjusting the rate at which the oil is sprayed into the vaporizing chamber and the temperature of the heating chamber. The heat in this chamber is created by burning distillate oil.

(c) Opacity and Density Detection System

Similar to the Mark II, this system consists of a light source and a photoelectric cell positioned at opposite ends of a light tube

protruding horizontally from each side of the smoke stack. The milliammeter, which registers the light received by the photocell, has a scale arranged so that 100 indicates no light and zero indicates free passage of light. When the operator adjusts the output of the light source to cause a full-scale deflection of the milliammeter, an opacity of zero is read. If the light is turned out, no light energy reaches the cell and the milliammeter reads 100 percent opacity.

Suggested Additional Reading

Guidelines for Development of A Quality Assurance Program: Volume IX - Visual Determination of Opacity Emissions from Stationary Sources. EPA Publication EPA-650/4-74-005-1, U.S. Environmental Protection Agency, Research Triangle Park, NC November, 1975.

Field Operations and Enforcement Manual for Air Pollution Control. Volume I; Organization and Basic Procedures, EPA Publication APTD-1100, U S Environmental Protection Agency, Research Triangle Park, NC, August 1972.

CHAPTER XIV.
OPACITY PROBLEMS CAUSED BY
WATER VAPOR

14.1. Introduction. The ease of monitoring a control area by visual observation has led to the enactment of regulations prohibiting plumes which obscure more than a certain percentage (frequently 40 percent) of an observer's view when he looks through the plume. One of the problems confronting control officials - using regulations which depend upon the visual determination of equivalent opacity - is that of evaluating plumes containing large quantities of water vapor. This water vapor, when it condenses and becomes visible, may make the plume 100 percent opaque even though the quantity of other particulate material is small enough so that the plume, if dry, would not be in violation of the opacity standard.

14.2 Is Water Vapor a Pollutant? The question arises as to whether equivalent opacity regulations should distinguish between those plumes that contain water vapor and those that do not. Water alone is not injurious to health, and is normally present in any atmosphere, either in the invisible vapor state or in a visible liquid state in the form of fog or clouds.

There are objections to water vapor emissions. Under certain topographical and meteorological conditions, the artificially created water vapor is a contributing factor to a higher frequency of ground fogs. These can be dangerous if they form in the vicinity of a highway or air field, because they decrease the visibility. Industrial accidents, also resulting from

the decreased visibility, may occur within the area of the emitting factory. In freezing weather, there is a possibility of increased ice formation because of the presence of higher atmospheric relative humidity. Even though the emission may be a pure water vapor, there is the possibility that a combination of the vapor and other substances in the air will create a harmful pollutant. This may occur in the vicinity of large power plants; when water vapor emitted from cooling towers in large quantities and sulfur oxides emitted from coal burning equipment combine in the air to form sulfuric acid mist, the damage to vegetation and materials may be far greater than would be expected if there was no water vapor emission.

Finally, there may be an objection based on aesthetic grounds, to dense plumes regardless of their composition. The average citizen cannot distinguish between a white plume, which is primarily water vapor and one of the same color containing only a small percentage of water.

14.3. Regulations Governing Wet Plumes. While ordinances in some air pollution codes make no distinction between the visible evaluation of water vapor and non-water plumes, other air pollution regulations do make provisions allowing for the emission of "uncombined water." Questions can arise about the interpretation of this term as to whether it means "chemically" uncombined. Even though the intent of the regulation may be to allow for only pure steam plumes, one may argue that no water vapor, either naturally or artificially produced, can condense unless it contains some particle as a nucleus for the water drop.

One method of "reading" wet plumes is to instruct the

plume inspector to observe these plumes at the point where the condensed water vapor portion of the plume has evaporated. This prevents the citation of a plume containing a dry opacity below the legal limit, but which because of the accompanying water, exceeds the opacity limit. This method, however, may protect a polluter because the dry opacity of his plume may exceed the legal limit near the stack. But at the point where the water evaporates, the plume has dispersed enough so that its opacity becomes legally acceptable.

Visible Identification of Water Vapor Plumes

14.4 Atmospheric Effects on Water Vapor. Water in the gaseous state (as water vapor) is invisible and is always present in the atmosphere. One of the measures of the volume of water vapor contained in the atmosphere is relative humidity; the more water vapor contained in a given amount of air, the higher the relative humidity content. When the air is "saturated" with water vapor, the relative humidity present is 100 percent. Any additional water vapor must condense out into the liquid state and will become visible in the plume.

The amount of the water vapor held in the air varies with the temperature of the air. Warm air can hold more water vapor than cold air. Consequently, air that is not saturated with water vapor may be cooled until it becomes saturated and the relative humidity then reaches 100 percent. If this cooling is done at constant pressure, the temperature at which saturation occurs is called the dew point. If the air is cooled below its dew point, it will be supersaturated and the excess water vapor condenses out into the liquid form of a cloud.

When wet plumes are initially created in a process, the gas temperature may be hot enough so that the water is invisible and is in the vapor form. If the plume is cooled sufficiently, either in the stack or in the atmosphere, then the plume becomes saturated with water vapor and condensation takes place. As the plume is mixed with the surrounding air, some of the moisture in the plume is transferred to the ambient air. This increases the relative humidity of the ambient air and decreases the relative humidity of the plume. When the relative humidity of the plume reaches 100 percent, the visible water begins to change by evaporation to an invisible vapor. In time the water plume completely disappears.

Under varying atmospheric temperatures or humidity conditions, two plumes that are emitted from a given process under identical conditions may form and then dissipate at different distances from the stack. In cold weather a plume may condense, and become visible, as soon as it leaves the stack. In hot weather not as much atmospheric cooling occurs and condensation may not take place until the effluent has moved some distance from the stack. This latter condition results in a detached plume.

Once formed, the plume disappears more quickly into the warmer air, which can hold additional water vapor without becoming saturated. For example, on two days with identical temperatures, the plume will persist for a longer distance on the day with a higher relative humidity, because the ambient air can hold less water vapor and cannot absorb additional moisture from the plume. Some materials, such as sulfur trioxide (SO_3) are hygroscopic and tend to attract the water vapor in the air. These plumes can remain visible to the observer for longer distances.

Identifying Visible Plumes. A pure water vapor plume disappears without a trace of dust. It evaporates quickly, mixes in all directions, and is characterized by its "wispiness."

When plumes are observed under varying atmospheric conditions, those containing large amounts of water vapor may be distinguished by their reactions. The wet plume may be detached from the stack in warmer weather, and it will persist for longer distances during periods of high relative humidity.

Plumes containing large amounts of sulfur trioxide will become visible as detached plumes when the relative humidity of the ambient air is high because the SO_3 is hygroscopic. For the same reason, they will also persist for longer distances than the pure water vapor plumes.

Typical Operations Which Discharge Water Vapor

14.5. Typical Operations Which Discharge Water Vapor.

- Drying operations:

- (1) Type of Equipment

- (a) Rotary dryers
 - (b) Spray dryers
 - (c) Drum dryers
 - (d) Tray and tunnel dryers

- (2) Type of Industry

- (a) Powdered milk
 - (b) Chemicals
 - (c) Pharmaceuticals
 - (d) Instant coffee
 - (e) Detergents
 - (f) Ores
 - (g) Paper

- Combustion operations in which fuels containing hydrogen and hydrocarbons are used
- Air pollution control operations which use water scrubbing to remove solids or pollutant gases:
 - (1) Typical Equipment
 - (a) Venturi scrubbers
 - (b) Packed towers
 - (c) Spray towers
- Cooling operations in which the heat is removed by water evaporation

Methods of Eliminating Visible Wet Plumes

14.6. Methods Eliminating Visible Wet Plumes.

Several methods are available to eliminate condensation of the stream plume from a stack:

(1) Dilution of the Plume with Heated Air.

Hot air can be mixed with the moist effluent to reduce the dew point and thus prevent the effluent from becoming super-saturated as it enters into the colder air. (An example of this method will be given later.)

(2) Superheating the Plume.

The plume is heated (before emission) to a temperature high enough to disperse the effluent in the atmosphere, before it has cooled to the dew point.

(3) Direct-Contact Condensation with Water.

The effluent can be cooled to its dew point by bringing the plume into direct contact

with cold water. There are several ways to accomplish this direct-contact cooling:

- (a) Surface water
- (b) Cooling tower
- (c) Air-fin cooler

(4) Indirect-Contact Condensation with a Surface Condenser

If contamination of the cooling water with the effluent is a problem, then the plume can be cooled by passing it through a tubular surface condenser containing circulating water. The three methods listed in A-3 above, can also be applied to indirect cooling.

(5) Combination Processes.

When the outdoor temperature is low, the problem of preventing condensation of the plume becomes more difficult because the air contains less water vapor before it becomes saturated. Under these conditions a combination of methods must be used, e.g., removing some of the moisture by condensation and then reheating the plume before discharging it.

Problems that may be encountered include:

- (1) Additional pollutants and excess energy use occurs when the plume is superheated or diluted with heated air.
- (2) When the water vapor in the plume is prevented from condensing in the atmosphere (by use of the direct-contact condenser cooling method) certain requirements must be considered:

- (a) A large quantity of cooling water must be available.
 - (b) The cooling water will pick up and convert some of the air contaminants into water pollutants.
 - (c) The cooling water will absorb some of the heat from the plume. If the volume of heat is large enough, thermal pollution may become a problem.
- (3) When the water vapor contained in a plume is condensed by direct or indirect contact condensation with water there will still be a discharge of water vapor into the atmosphere. The condensate will be transferred from the stack, to a cooling tower or the surface of a river or lake, where it may become less objectionable to the community.
- (4) The most economical method, on an annual operating cost basis, is direct condensation with natural surface water; however, natural water is not always available. The only method that minimizes air, water, and thermal pollution (condensation with a surface condenser using an air-fin cooler) is the second most expensive one. In tall stacks, such as found in power plants, it is necessary to heat the effluent gases (when scrubbers are used) to obtain adequate buoyancy of the gases in the stack.

9

Reading Water Vapor Plumes

14.7. If the condensed water vapor plume is detached, opacity determinations can be made immediately at

the stack exit, i.e., before the water vapor begins to condense.

If the water vapor plume is attached to the stack, readings should be made at the point where the water droplets have revaporized completely. This point may be some distance downwind thus allowing the pollutants to become diluted by mixing with the ambient air. The further downwind this point is, the more dilute will be the pollutants and the lower the opacity readings will become, which of course, tends to act in favor of the source.

If the inspector has any question about the quantity of pollutants being emitted by a source and is unable to take a reading close to the stack because of the condensed water vapor plume, a source test should be ordered.

The best way of handling the problem is to make the visit to the plant when there is a good possibility that the condensed water vapor plume will not be present. Using a psychrometric chart, according to the procedures of Section 14.9 in conjunction with estimates of meteorological and effluent conditions, and a few minutes of computation, the inspector may determine whether or not there is a good possibility that the water vapor in the plume will condense. This procedure could save the inspector a wasted trip to the plant in question. An example of the use of the psychrometric chart is given below.

Description of the Psychrometric Chart

14.8. A psychrometric chart is a graphical solution of various temperature and humidity states of air and water vapor mixtures. Each point on the chart represents

one unique combination of the following atmospheric properties:

- (1) Dry bulb temperature, which is the actual temperature of the gas.
- (2) Wet bulb temperature, which is the temperature indicated by a thermometer that has its bulb covered with water and placed in a stream of moving air.
- (3) Relative humidity, which is the ratio of the partial pressure to the saturation vapor pressure of water, at the same temperature.
- (4) Humidity ratio, which is the ratio of the mass of water vapor present per unit mass of dry air.
- (5) Specific volume of dry air, which is the volume occupied by unit mass of dry air.

If any two of these parameters are known, then the state point on the psychrometric chart is defined.

The psychrometric chart for normal atmospheric pressure conditions is shown in Figure 14-1, which is sufficiently accurate for the estimates involved in this procedure for most parts of the country.

The curved line along the left side of the chart represents the 100 percent relative humidity line, or the saturation line. Any state point to the left of this line, or the path of any process crossing this line, will normally be accompanied by condensation of the water vapor resulting in the formation of a steam plume. As can be seen from the psychrometric chart:

- (a) Toward the lower end of the ambient temperature range it takes very little

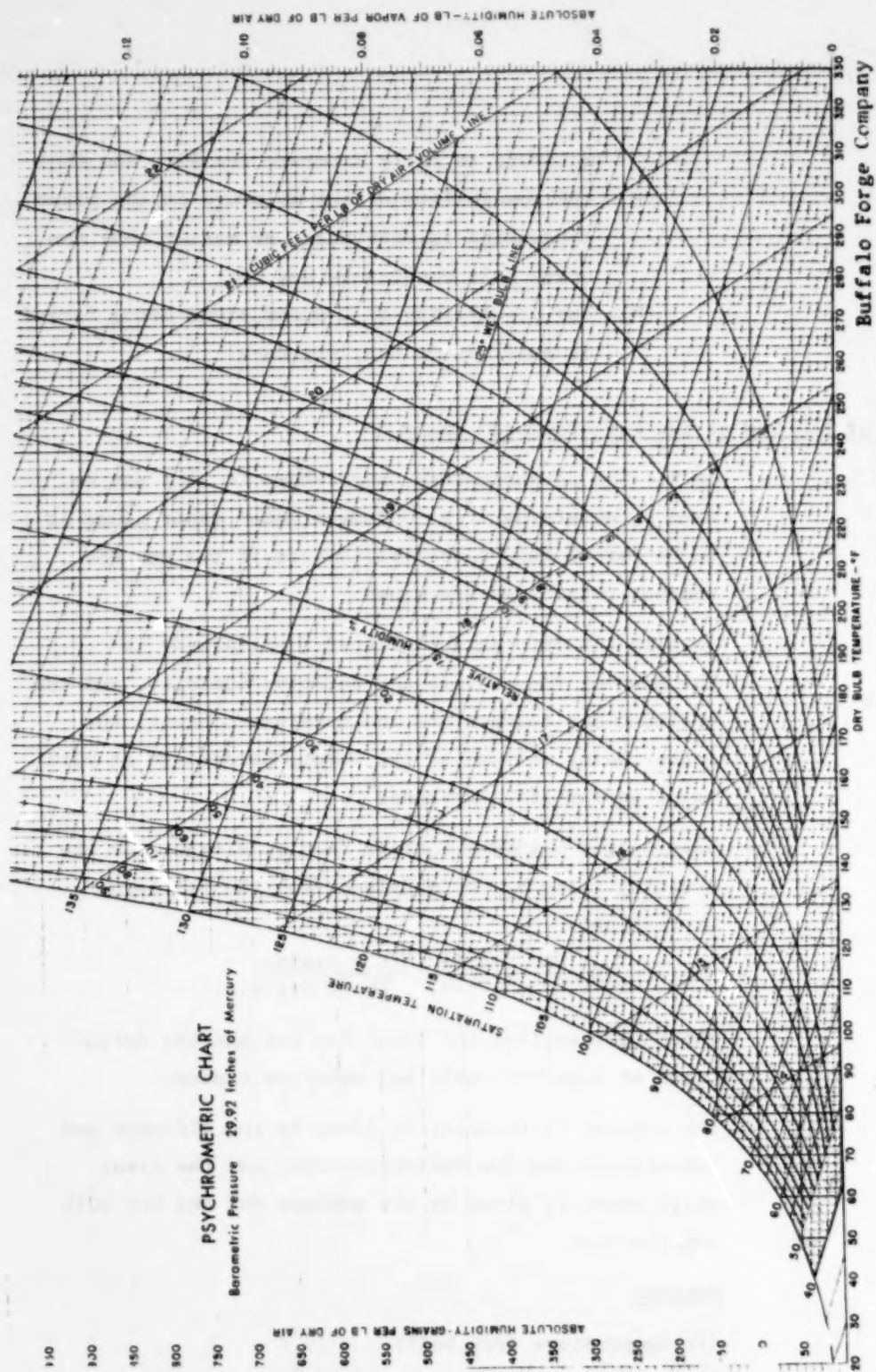


Figure 14-1. PSYCHROMETRIC CHART (Sea Level Conditions)

moisture to fully saturate the air, and thus the possibility of the moisture in the plume condensing is very high, no matter what the stack exit conditions may be;

- (b) The possibility of a steam plume being formed is smallest on hot, dry days.

Example of the Use of the Psychrometric Chart

14.9. The psychrometric chart shown in 14.1 may be used to determine if a condensed water vapor plume is to be formed from a specific source if the ambient weather conditions are known.

Usually the information given (or estimated) is the ambient temperature and relative humidity, and the effluent gas temperature and moisture content, the latter being defined as the volume percentage of water vapor in the effluent gases.

Knowing the moisture content (M.C.), a value for the humidity ratio may be obtained from the following expression:

$$\text{Humidity Ratio} = \frac{4354 (\text{M.C.}) \text{ Grains}}{1 - \text{M.C. Lb of Dry Air}}$$

which follows from the Ideal Gas Law and the definitions of humidity ratio and moisture content.

The initial state point is given by the effluent gas temperature and the humidity ratio, and the final state point is given by the ambient wet and dry bulb temperatures.

Ambient

Air Temperature (dry bulb)	= 70°F
Wet Bulb Temperature	= 60°F
Barometric Pressure	= 29.92 inches Hg

Effluent Gas

Exhaust Temperature (dry bulb) = 160°F

Moisture Content = 16.8%

Substituting these values into the expression for the humidity ratio gives:

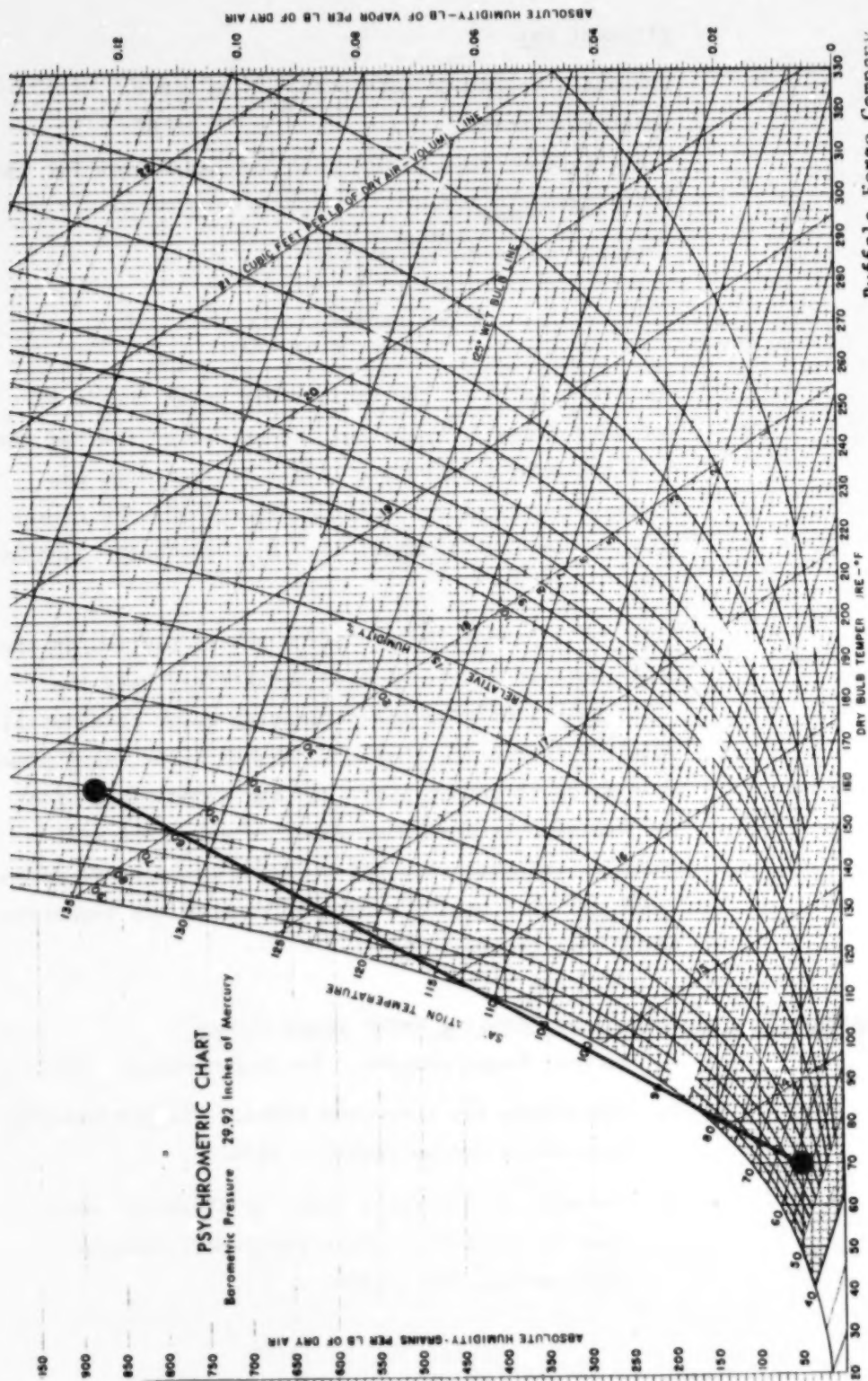
$$\begin{aligned}\text{Humidity Ratio} &= \frac{4354 (0.168)}{1-0.168} \\ &= 880 \frac{\text{Grains}}{\text{Lb. of dry air}}\end{aligned}$$

The state point of the ambient air is at the intersection of the 70°F dry bulb temperature line and the 60°F wet bulb temperature line. The effluent gas state point is at the intersection of the 880 grains per pound of dry air line and the 160°F dry bulb temperature line.

Figure 14.2 shows the two state points plotted on the psychrometric chart. A line connecting these two state points crosses the saturation curve at about 112°F and 84°F indicating that a condensed water vapor plume is a distinct possibility. As the plume mixes with the ambient air the water vapor in the plume will begin to condense when the effluent temperature reaches 112°F and will begin to revaporize when its temperature is further cooled to 84°F.

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3. Crocker, B. B., Water Vapor in Effluent Gases: What to do about Opacity Problems. Chemical Engineering, June, 1968.



Buffalo Forge Company

Figure 14-2. PSYCHROMETRIC CHART (Sea Level Conditions)

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- Citation: Lloyd A. Fry Company v. Utah Air Conservation Committee, 545 P 2d 495 (Utah, 1975) APCA Journal, August, 1976, Volume 26, No. 8, pg. 819.
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STATIONARY SOURCES

METHOD 9—VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

Many stationary sources discharge visible emissions into the atmosphere; these emissions are usually in the shape of a plume. This method involves the determination of plume opacity by qualified observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of plume opacity. The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable and some of which may not be controllable in the field. Variables which can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: Angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to a plume emitted from a rectangular stack with a large length to width ratio. The method includes specific criteria applicable to these variables.

Other variables which may not be controllable in the field are luminance and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of a plume as viewed by an observer, and can affect the ability of the observer to accurately assign opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a contrasting background. It follows from this, and is confirmed by field trials, that the opacity of a plume, viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy. However, the potential for a positive error is also the greatest

when a plume is viewed under such contrasting conditions. Under conditions presenting a less contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminance contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a plant operator will be cited for a violation of opacity standards due to observer error.

Studies have been undertaken to determine the magnitude of positive errors which can be made by qualified observers while reading plumes under contrasting conditions and using the procedures set forth in this method. The results of these studies (field trials) which involve a total of 769 sets of 25 readings each are as follows:

(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error of less than "5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity.

(2) For white plumes (170 sets at a smoke generator, 168 sets at a coal-fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity.

The positive observational error associated with an average of twenty-five readings is therefore established. The accuracy of the method must be taken into account when determining possible violations of applicable opacity standards.

For a set, positive error—average opacity determined by observers' 25 observations—average opacity determined from transmitter's 25 recordings.

S-395
121:1579

1. Principle and applicability.

1.1 Principle. The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources pursuant to § 60.11(b) and for qualifying observers for visually determining opacity of emissions.

2. Procedures. The observer qualified in accordance with paragraph 3 of this method shall use the following procedures for visually determining the opacity of emissions:

2.1 Position. The qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back. Consistent with maintaining the above requirement, the observer shall, as much as possible, make his observations from a position such that his line of vision is approximately perpendicular to the plume direction, and when observing opacity of emissions from rectangular outlets (e.g. roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The observer's line of sight should not include more than one plume at a time when multiple stacks are involved, and in any case the observer should make his observations with his line of sight perpendicular to the longer axis of such a set of multiple stacks (e.g. stub stacks on baghouses).

2.2 Field records. The observer shall record the name of the plant, emission location, type facility, observer's name and emission, and the date on a field data sheet (Figure 9-1). The time, estimated distance to the emission location, approximate wind direction, estimated wind speed, description of the sky condition (presence and color of clouds), and plume background are recorded on a field data sheet at the time opacity readings are initiated and completed.

2.3 Observations. Opacity observations shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present. The observer shall not look continuously at the plume, but instead shall observe the plume momentarily at 15-second intervals.

2.3.1 Attached steam plumes. When condensed water vapor is present within the plume as it emerges from the emission outlet, opacity observations shall be made beyond the point in the plume at which condensed water vapor is no longer visible. The observer shall record the approximate distance from the emission outlet to the point in the plume at which the observations are made.

2.3.2 Detached steam plume. When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emissions should be evaluated at the emission outlet prior to the condensation of water vapor and the formation of the steam plume.

2.4 Recording observations. Opacity observations shall be recorded to the nearest 5 percent at 15-second intervals on an observational record sheet. (See Figure 9-3 for an example.) A minimum of 24 observations shall be recorded. Each momentary observation recorded shall be deemed to represent the average opacity of emissions for a 15-second period.

2.5 Data Reduction. Opacity shall be determined as an average of 24 consecutive observations recorded at 15-second intervals. Divide the observations recorded on the record sheet into sets of 24 consecutive observations. A set is composed of any 24 consecutive observations. Sets need not be consecutive in time and in no case shall two sets overlap. For each set of 24 observations, calculate the average by summing the opacity of the 24 observations and dividing this sum by 24. If an applicable standard specifies an averaging time requiring more than 24 observations, calculate the average for all observations made during the specified time period. Record the average opacity on a record sheet. (See Figure 9-1 for an example.)

3. Qualifications and testing.

3.1 Certification requirements. To receive certification as a qualified observer, a candidate must be tested and demonstrate the ability to assign opacity readings in 5 percent increments to 25 different black plumes and 25 different white plumes, with an error not to exceed 15 percent opacity on any one reading and an average error not to exceed 7.5 percent opacity in each category. Candidates shall be tested according to the procedures described in paragraph 3.2. Smoke generators used pursuant to paragraph 3.2 shall be equipped with a smoke meter which meets the requirements of paragraph 3.3.

The certification shall be valid for a period of 6 months, at which time the qualification procedure must be repeated by any observer in order to retain certification.

3.2 Certification procedure. The certification test consists of showing the candidate a complete run of 50 plumes—25 black plumes and 25 white plumes—generated by a smoke generator. Plumes within each set of 25 black and 25 white runs shall be presented in random order. The candidate assigns an opacity value to each plume and records his observation on a suitable form. At the completion of each run of 50 readings, the score of the candidate is determined. If a candidate fails to qualify, the complete run of 50 readings must be repeated in any test. The smoke test may be administered as part of a smoke school or training program, and may be preceded by training or familiarization runs of the smoke generator during which candidates are shown black and white plumes of known opacity.

3.3 Smoke generator specifications. Any smoke generator used for the purposes of paragraph 3.2 shall be equipped with a smoke meter installed to measure opacity across the diameter of the smoke generator stack. The smoke meter output shall display in-stack opacity based upon a pathlength equal to the stack exit diameter, on a full 0 to 100 percent chart recorder scale. The smoke meter optical design and performance shall meet the specifications shown in Table 9-1.

The smoke meter shall be calibrated as prescribed in paragraph 3.3.1 prior to the conduct of each smoke reading test. At the completion of each test, the zero and span drift shall be checked and if the drift exceeds ± 1 percent opacity, the condition shall be corrected prior to conducting any subsequent test runs. The smoke meter shall be demonstrated, at the time of installation, to meet the specifications listed in Table 9-1. This demonstration shall be repeated following any subsequent repair or replacement of the photocell or associated electronic circuitry including the chart recorder or output meter, or every 6 months, whichever occurs first.

TABLE 9-1—SMOKE METER DESIGN AND PERFORMANCE SPECIFICATIONS

Parameter:	Specification
a. Light source----	Incandescent lamp operated at nominal rated voltage.
b. Spectral response of photocell.	Photopic spectral response of the human eye—reference 4.3).
c. Angle of view----	15° maximum total angle.
d. Angle of projection.	15° maximum total angle.
e. Calibration error.	$\pm 3\%$ opacity, maximum.
f. Zero and span drift.	$\pm 1\%$ opacity, 30 minutes.
g. Response time---	≤ 5 seconds.

3.3.1 Calibration. The smoke meter is calibrated after allowing a minimum of 30 minutes warmup by alternately producing simulated opacity of 0 percent and 100 percent. When stable response at 0 percent or 100 percent is noted, the smoke meter is adjusted to produce an output of 0 percent or 100 percent, as appropriate. This calibration shall be repeated until stable 0 percent and 100 percent readings are produced without adjustment. Simulated 0 percent and 100 percent opacity values may be produced by alternately switching the power to the light source on and off while the smoke generator is not producing smoke.

3.3.2 Smoke meter evaluation. The smoke meter design and performance are to be evaluated as follows:

3.3.2.1 Light source. Verify from manufacturer's data and from voltage measurements made at the lamp, as installed, that the lamp is operated within ± 5 percent of the nominal rated voltage.

3.3.2.2 Spectral response of photocell. Verify from manufacturer's data that the photocell has a photopic response; i.e., the spectral sensitivity of the cell shall closely approximate the standard spectral-luminosity curve for photopic vision which is referenced in (b) of Table 9-1.

3.3.2.3 Angle of view. Check construction geometry to ensure that the total angle of view of the smoke plume, as seen by the photocell, does not exceed 15° . The total angle of view may be calculated from: $\theta = 2 \tan^{-1} d/2L$, where θ = total angle of view; d = the sum of the photocell diameter + the diameter of the limiting aperture; and L = the distance from the photocell to the limiting aperture. The limiting aperture is the point in the path between the photocell and the smoke plume where the angle of view is most restricted. In smoke generator smoke meters this is normally an orifice plate.

3.3.2.4 Angle of projection. Check construction geometry to ensure that the total angle of projection of the lamp on the smoke plume does not exceed 15° . The total angle of projection may be calculated from: $\theta = 2 \tan^{-1} d/2L$, where θ = total angle of projection; d = the sum of the length of the lamp filament + the diameter of the limiting aperture; and L = the distance from the lamp to the limiting aperture.

3.3.2.5 Calibration error. Using neutral-density filters of known opacity, check the error between the actual response and the theoretical linear response of the smoke

meter. This check is accomplished by first calibrating the smoke meter according to 3.3.1 and then inserting a series of three neutral-density filters of nominal opacity of 20, 50, and 75 percent in the smoke meter pathlength. Filters calibrated within ± 3 percent shall be used. Care should be taken when inserting the filters to prevent stray light from affecting the meter. Make a total of five nonconsecutive readings for each filter. The maximum error on any one reading shall be 3 percent opacity.

3.3.2.6 Zero and span drift. Determine the zero and span drift by calibrating and operating the smoke generator in a normal manner over a 1-hour period. The drift is measured by checking the zero and span at the end of this period.

3.3.2.7 Response time. Determine the response time by producing the series of five simulated 0 percent and 100 percent opacity values and observing the time required to reach stable response. Opacity values of 0 percent and 100 percent may be simulated by alternately switching the power to the light source off and on while the smoke generator is not operating.

4. References.

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4.2 Weisburd, Melvin I., Field Operations and Enforcement Manual for Air, U.S. Environmental Protection Agency, Research Triangle Park, N.C., APTD-1100, August 1972, pp. 4.1-4.36.

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PAGE of

COMPANY	HOURS OF OBSERVATION
LOCATION	OBSERVER
TEST NUMBER	OBSERVER CERTIFICATION DATE
DATE	OBSERVER AFFILIATION
TYPE FACILITY	POINT OF EMISSIONS
CONTROL DEVICE	HEIGHT OF DISCHARGE POINT

[illegible]

CLOCK TIME

OBSERVER LOCATION
Distance to Discharge

Direction from Discharge

Height of Observation Point

BACKGROUND DESCRIPTION

WEATHER CONDITIONS
Wind Direction

Wind Speed

Ambient Temperature

SKY CONDITIONS (clear, overcast, % clouds, etc.)

PLUME DESCRIPTION

Color

Distance Visible

OTHER INFORMATION

SUMMARY OF AVERAGE OPACITY

[illegible]

Readings ranged from ___ to ___ % opacity

The source was/was not in compliance with _____ at the time evaluation was made.

FIGURE 9-2 OBSERVATION RECORD
(Continued)

FIGURE 9-2 OBSERVATION RECORD

PAGE ____ OF ____

PAGE ____ OF ____

COMPANY _____
 LOCATION _____
 TEST NUMBER _____
 DATE _____

OBSERVER _____
 TYPE FACILITY _____
 POINT OF EMISSIONS _____

COMPANY _____
 LOCATION _____
 TEST NUMBER _____
 DATE _____

OBSERVER _____
 TYPE FACILITY _____
 POINT OF EMISSIONS _____

Hr.	Min.	Seconds					STEAM PLUME (check if applicable)		COMMENTS
		0	15	30	45		Attached	Detached	
	30								
	31								
	32								
	33								
	34								
	35								
	36								
	37								
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	58								
	59								

Hr.	Min.	Seconds					STEAM PLUME (check if applicable)		COMMENTS
		0	15	30	45		Attached	Detached	
	0								
	1								
	2								
	3								
	4								
	5								
	6								
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[FR Doc. 74-36150 Filed 11-11-74; 8:45 am.]

CHAPTER XVI

FEDERAL STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES OF AIR POLLUTION

A Summary of Regulations

Linda S. Chaput

U. S. Environmental Protection Agency

In order to make the information in the *Federal Register* more easily accessible, a summary has been prepared of Federal standards of performance for new stationary sources of air pollution. The standards of performance promulgated by the Environmental Protection Agency in the period from December 1971 through June 1976 are presented in tabular form.

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Anyone who must use the *Federal Register* frequently to refer to regulations published by Federal agencies is well aware of the problems of sifting through the many pages to extract the "meat" of a regulation. Although regulatory language is necessary to make the intent of

a regulation clear, a more concise reference to go to when looking up a particular standard would be helpful. With this in mind, the following table was developed to assist those who work with Federal standards of performance for new stationary sources of air pollution.

The table lists the standards of performance which the Environmental Protection Agency (EPA) has promulgated since December 1971. It includes the categories of stationary sources and the affected facilities to which the standards apply; the pollutants which

Standards of Performance – 40 CFR Part 60.

Source category	Affected facility	Pollutant	Emission level	Monitoring requirement
Subpart D:				
Steam generators (>250 million Btu/hr)	Coal fired boilers	Particulate Opacity SO ₂ NO _x (except lignite and coal refuse)	0.10 lb/10 ⁶ Btu 20% 1.2 lb/10 ⁶ Btu 0.70 lb/10 ⁶ Btu	No requirement Continuous Continuous Continuous
<i>Promulgated</i> 12/23/71 (36 FR 24876)				
<i>Revised</i> 7/26/72 (37 FR 14877) 6/14/74 (39 FR 20790) 1/16/75 (40 FR 2803) 10/6/75 (40 FR 46250)	Oil fired boilers	Particulate Opacity SO ₂ NO _x	0.10 lb/10 ⁶ Btu 20% ; 40% 2 min/hr 0.80 lb/10 ⁶ Btu 0.30 lb/10 ⁶ Btu	No requirement Continuous Continuous Continuous
	Gas fired boilers	Particulate Opacity NO _x	0.10 lb/10 ⁶ Btu 20% 0.20 lb/10 ⁶ Btu	No requirement No requirement Continuous
Subpart E:				
Incinerators (>50 tons/day)	Incinerators	Particulate	0.08 gr / dscf corrected to 12% CO ₂	No requirement
<i>Promulgated</i> 12/23/71 (36 FR 24876)				
<i>Revised</i> 6/14/74 (39 FR 20790)				
Subpart F:				
Portland cement plants	Kiln	Particulate Opacity	0.30 lb/ton 20%	No requirement No requirement
<i>Promulgated</i> 12/23/71 (36 FR 24876)	Clinker cooler	Particulate Opacity	0.10 lb/ton 10%	No requirement No requirement
<i>Revised</i> 6/14/74 (39 FR 20790) 11/12/74 (39 FR 39874) 10/6/75 (40 FR 46250)	Fugitive Emission points	Opacity	10%	No requirement
Subpart G:				
Nitric acid plants	Process equipment	Opacity NO _x	10% 3.0 lb/ton	No requirement Continuous
<i>Promulgated</i> 12/23/71 (36 FR 24876)				
<i>Revised</i> 5/23/73 (38 FR 13562) 6/14/74 (39 FR 20790) 10/6/75 (40 FR 46250)				
Subpart H:				
Sulfuric acid plants	Process equipment	SO ₂ Acid mist Opacity	4.0 lb/ton 0.15 lb/ton 10%	Continuous No requirement No requirement
<i>Promulgated</i> 12/23/71 (36 FR 24876)				
<i>Revised</i> 5/23/73 (38 FR 13562) 6/14/74 (39 FR 20790) 10/6/75 (40 FR 46250)				

Source category	Affected facility	Pollutant	Emission level	Monitoring requirement
Subpart I:				
Asphalt concrete plants	Dryers; screening and weighing systems; storage, transfer, and loading systems; and dust handling equipment	Particulate	0.04 gr/dscf (90 mg/dscm)	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)		Opacity	20%	No requirement
<i>Revised</i> 10/6/75 (40 FR 46250)				
Subpart J:				
Petroleum refineries	Catalytic cracker	Particulate	1.0 lb/1000 lb	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)		Opacity	30% (3 min. exemption)	Continuous
		CO	0.05%	Continuous
<i>Revised</i> 10/6/75 (40 FR 46250)	Fuel gas combination	SO ₂	0.1 gr H ₂ S/dscf (230 mg/dscm)	Continuous
Subpart K:				
Storage vessels for petroleum liquids	Storage tanks >40,000 gal. capacity	Hydrocarbons	For vapor pressure 78-570 mm Hg, equip with floating roof, vapor recovery system, or equivalent; for vapor pressure >570 mm Hg, equip with vapor recovery system or equivalent	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)				
<i>Revised</i> 4/17/74 (39 FR 13776) 6/14/74 (39 FR 20790)				
Subpart L:				
Secondary lead smelters	Reverberatory and blast furnaces	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
		Opacity	20%	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)	Pot furnaces	Opacity	10%	No requirement
<i>Revised</i> 4/17/74 (39 FR 13776) 10/6/75 (40 FR 46250)				
Subpart M:				
Secondary brass and bronze plants	Reverberatory furnace	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
		Opacity	20%	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)	Blast and electric furnaces	Opacity	10%	No requirement
<i>Revised</i> 10/6/75 (40 FR 46250)				
Subpart N:				
Iron and steel plants	Basic oxygen process furnace	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
<i>Promulgated</i> 3/8/74 (39 FR 9308)				

Source category	Affected facility	Pollutant	Emission level	Monitoring requirement
Subpart O:				
Sewage treatment plants	Sludge incinerators	Particulate	1.30 lb/ton	Mass or volume of sludge
		Opacity	20%	No requirement
	<i>Promulgated 3/8/74 (39 FR 9308)</i>			
<i>Revised 4/17/74 (39 FR 13776)</i>				
<i>5/3/74 (39 FR 15396)</i>				
<i>10/6/75 (40 FR 46250)</i>				
Subpart P:				
Primary copper smelters	Dryer	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
	Roaster, smelting furnace,* copper converter	Opacity	20%	Continuous
		SO ₂	0.065%	Continuous
<i>Promulgated 1/15/76 (41 FR 2331)</i>				
<i>Revised 2/26/76 (41 FR 8346)</i>				
* Reverberatory furnaces that process high-impurity feed materials are exempt from SO ₂ standard				
Subpart Q:				
Primary zinc smelters	Sintering machine	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
	Roaster	Opacity	20%	Continuous
		SO ₂	0.065%	Continuous
<i>Promulgated 1/15/76 (41 FR 2331)</i>				
<i>Revised 2/26/76 (41 FR 8346)</i>				
Subpart R:				
Primary lead smelters	Blast or reverberatory furnace, sintering machine discharge end	Particulate	0.022 gr/dscf (50 mg/dscm)	No requirement
	Sintering machine, electric smelting furnace, converter	Opacity	20%	Continuous
		SO ₂	0.065%	Continuous
<i>Promulgated 1/15/76 (41 FR 2331)</i>				
Subpart S:				
Primary aluminum reduction plants	Potroom group	(a) Total fluorides	2.0 lb/ton	No requirement
	(a) Soderberg plant	Opacity	10%	No requirement
	(b) Prebake plant	(b) Total fluorides	1.9 lb/ton	No requirement
<i>Promulgated 1/26/76 (41 FR 3825)</i>				
<i>Revised 4/17/74 (39 FR 13776)</i>				
<i>5/3/74 (39 FR 15396)</i>				
<i>10/6/75 (40 FR 46250)</i>				
Subpart T:				
Primary aluminum anode bake plants	Anode bake plants	Total fluorides	0.1 lb/ton	No requirement
		Opacity	20%	No requirement
	<i>Promulgated 1/26/76 (41 FR 3825)</i>			

are regulated and the levels to which they must be controlled; and the requirements for monitoring emissions and operating parameters. The stan-

dards apply to new, modified, and reconstructed stationary sources of air pollution and are set at levels required to control emissions of air pollutants to

the greatest degree practicable using the best systems of emission reduction, considering the costs of such reduction.

Source category	Affected facility	Pollutant	Emission level	Monitoring requirement
Subpart T:				
Phosphate fertilizer plants <i>Promulgated</i> 8/6/75 (40 FR 33152)	Wet process phosphoric acid	Total fluorides	0.02 lb/ton	Total pressure drop across process scrubbing system
Subpart U:	Superphosphoric acid	Total fluorides	0.01 lb/ton	Total pressure drop across process scrubbing system
Subpart V:	Diammonium phosphate	Total fluorides	0.06 lb/ton	Total pressure drop across process scrubbing system
Subpart W:	Triple super-phosphate	Total fluorides	0.2 lb/ton	Total pressure drop across process scrubbing system
Subpart X:	Granular triple superphosphate	Total fluorides	5.0×10^{-4} lb/hr/ton	Total pressure drop across process scrubbing system
Subpart Y:				
Coal preparation plants <i>Promulgated</i> 1/15/76 (41 FR 2232)	Thermal dryer	Particulate	0.031 gr/dscf (0.070 g/dscm)	Temperature Scrubber pressure loss Water pressure
		Opacity	20%	No requirement
	Pneumatic coal cleaning equipment	Particulate	0.018 gr/dscf (0.040 g/dscm)	No requirement
		Opacity	10%	No requirement
	Processing and Conveying equipment, storage systems, transfer and loading systems	Opacity	20%	No requirement
Subpart Z:				
Ferroalloy production facilities <i>Promulgated</i> 5/4/76 (41 FR 18497) <i>Revised</i> 5/20/76 (41 FR 20659)	Electric submerged arc furnaces	Particulate	0.99 lb/Mw-hr (0.45 kg/Mw-hr) ("high silicon alloys") 0.51 lb/Mw-hr (0.23 kg/Mw-hr) (chrome and manganese alloys) No visible emissions may escape furnace capture system	No requirement Flowrate monitoring in hood

Before developing standards for a particular source category, EPA must first identify the pollutants emitted and determine that they contribute signifi-

cantly to air pollution which endangers public health or welfare. The standards are then developed and proposed in the *Federal Register*. After a period of time

during which the public is encouraged to submit comments on the proposal, appropriate revisions are made to the regulations and they are promulgated in

Source category	Affected facility	Pollutant	Emission level	Monitoring requirement
Ferroalloy production facilities (cont.)			No visible emission may escape tapping system for >40% of each tapping period	Flowrate monitoring in hood
		Opacity	15%	Continuous
		CO	20% volume basis	No requirement
	Dust handling equipment	Opacity	10%	No requirement
Subpart AA:				
Iron and steel plants	Electric arc Furnaces	Particulate	0.0052 gr/dscf (12 mg/dscm)	No requirement
		Opacity		
		(a) control device	3%	Continuous
Promulgated 9/23/75 (40 FR 43850)		(b) shop roof	0, except 20%—charging 40%—tapping	Flowrate monitoring in capture hood Pressure monitoring in DSE system
	Dust handling equipment	Opacity	10%	No requirement

the *Federal Register*. To cite such a promulgation, it is common to refer to it by volume and page number, i.e., 36 FR 24876, which means Volume 36, page 24876 of the *Federal Register*. The table gives such references for the promulgation and subsequent revisions of each standard listed.

Once a year, all regulations that have been published in the *Federal Register* during that year are codified for inclusion in the *Code of Federal Regulations* (CFR). Only the regulations are codified; the preambles which appear with the regulations in the *Federal Register* are not included in the CFR. The CFR is divided into 50 titles which represent

broad areas subject to Federal regulation. Each title is divided into chapters which usually bear the name of the issuing agency. Each chapter is further subdivided into parts covering specific regulatory areas. EPA's regulations are included in Title 40—Protection of the Environment, Chapter I—Environmental Protection Agency. Breaking the classification down further, Subchapter C covers regulations concerning Air Programs which is then broken down into more specific parts. Part 60 is titled "Standards of Performance for New Stationary Sources," thus the reference in the table heading to 40 CFR Part 60.

The table lists all standards of performance promulgated through June 1976. The complete regulations for these standards are included in the CFR which was revised July 1, 1976, and contains Parts 60 to 99. Any regulations proposed or promulgated between July 1, 1976, and July 1, 1977, will appear in the *Federal Register* (published daily except Saturday and Sunday) and will be codified in the 1977 revision to the CFR. Anyone wishing to subscribe to the *Federal Register* or purchase the CFR should contact the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

CHAPTER XVII.
VISIBLE EMISSION STANDARDS
OF THE UNITED STATES

Volume 2 of "The World's Air Quality Management Standards," EPA publication No. EPA 650/9-75-001-b by W. Martin and Arthur C. Stern, gives visible emission standards in existence as of 1973 for 49 states, the District of Columbia and Puerto Rico expressed in terms of emissions from mobile sources, aircraft, automobiles, trucks and buses, locomotives, and marine vessels, as well as from a wide variety of stationary sources and the combustion of wood, fossil fuels, and refuse. This publication is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Another source of information would be reference to the "Environmental Reporter" available in most libraries.

With the requirement of State Implementation Plans by Section 110 of the Clean Air Act, as amended, all 55 states and territories have adopted Ringelmann and equivalent opacity provisions, now commonly referred to as "opacity regulations." The standard predominantly adopted by the states is 20 percent opacity; however, a few agencies and the Federal Government in some of their new source performance standards are adopting 10 percent and in some cases zero opacity regulations for many source categories. There is now considerable test data available to support new source performance standards with very low opacity limitations.